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PARS CLIMATOLOGICA ET CHOROLOGICA
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CURAT: ILONA BÁRÁNY-KEVEI

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MODELLING THE MAXIMUM DEVELOPMENT OF URBAN HEAT ISLAND WITH THE APPLICATION OF GIS BASED SURFACE PARAMETERS IN SZEGED (PART 1): TEMPERATURE, SURVEYING AND GEOINFORMATICAL MEASUREMENTS METHODS

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Összefoglalás – Vizsgálatunk célja az éves átlagos hősziget kialakulását, méretét és területi szerkezetét befolyásoló speciális városi struktúra, ezen belül a geometriai szerkezet és beépítettség hatásának számszerűsítése. A kétrészes tanulmányban a korábban már alkalmazott égboltláthatósági index és beépítettségi tényezők mellett az épületkompaktság klímaalakító szerepét is vizsgáljuk. A szakirodalom szerint is teljesen új paraméter három dimenzióban egyszerre jellemzi az épületek térfogatát, valamint tagoltságukat és elsősorban termodinamikai szempontból játszik fontos szerepet. Az első részben a városklíma egyes sajátosságainak áttekintése után bemutatjuk a vizsgált területet (Szeged), valamint a hőmérsékleti, terepi és térinformatikai felmérési módszereket, amelyek – a modell megalkotásának érdekében – elengedhetetlenül szükségesek a hőmérséklet és a különböző felszínparaméterek városon belüli eloszlásának meghatározásához.

Summary – The aim of our research is to reveal quantitatively the effect of the peculiar urban structure on the development, magnitude and spatial distribution of the mean annual urban heat island. In this two-part study, besides the earlier applied sky view factor and different built-up parameters, we examine the climate modification role of the building compactness. This new parameter characterises the volume, plan area and thermodinamical role of the buildings at the same time. In the first part, after a general overview of some features of the urban climate, we will present the investigated area in Szeged, then the applied temperature, surveying and geoinformatical measurement methods. In order to establish the model, these methods are necessary to determine the intra-urban spatial distribution of the temperature and the different surface parameters.

Key words: urban heat island, urban surface parameters, geoinformatic methods, Szeged, Hungary

1. INTRODUCTION

In settlement environments the energy and water balance of the area are influenced significantly by the changed surface cover, which leads indirectly to the alteration of climate above the cities on a local scale. Among the changes the excess of urban temperatures (urban heat island – *UHI*) appears in the most identical way (*Landsberg,* 1981). This excess influences fundamentally the comfort sensation of the inhabitants. The effect has double characteristics, because in summer it is stressful with slowly cooling air at night, but in winter this same influence is advantageous, because the heating demand of buildings and the length of heating period decrease in the area of cities (*Unger and Sümeghy,* 2002). Therefore its research serves with important information, for example for urban planning (*Kuttler,* 2005). Furthermore, the composition of urban vegetation is changed and postponement of phenological phases is observable (*Lakatos and Gulyás,* 2003).

It is difficult to define the factors affecting the development and intensity of *UHI,* to determine their role quantitatively and to model this because of the complex vertical and horizontal structure of the city and because of the artificial emission of heat and pollutants. Detailed data collection is also complicated and demands significant technical investments.

The aim of our research is to calculate the effect of the special urban structure (the 3D geometric structure, and built-up ratio), on the development, magnitude and spatial distribution of the annual mean *UHI.* The question is how far it is possible to specify the description of strength and structure of urban heat island when applying these surface parameters in statistical model-equations. In this two-part study the climate modifying role of the so-called weighted volumetric compactness of buildings is examined in addition to the sky view factor (*SVF*) and built-up ratio (*B*) applied earlier (*Bottyán and Unger,* 2003; *Bottyán et al.,* 2005). It is a new parameter, which characterizes the volume and structure of buildings in 3D, and it plays a significant role from the thermodynamical point of view. In this first part we present the study area (Szeged), also the methods of temperature measurements, surveying works and geoinformatics, which are necessary to determine the distribution of the temperature and different surface parameters within the city.

2. STUDY AREA

2.1. Geographical situation and climatic characteristics of the city of Szeged

Szeged is situated in the southern part of the Great Hungarian Plain, where the river Maros flows into the river Tisza. On the surface there are Holocene sediments with low relief. According to Trewartha's classification Szeged belongs to the climatic type D.1 (continental climate with longer warm season), similarly to the predominant part of the country.

The regional division of *Péczely* (1979) is applied in the more detailed climatic description. According to this the study area belongs to the warm-dry climatic region, so its aridity index is more than 1.15, the average temperature of the vegetation period is more than 15°C. The annual sum of global radiation is around the country average (4700 MJm^{-2}), while the sunshine duration is high above the average (2023 h), the percentage of clouds (57%) is under the average of the country. The prevailing winds are N and NW, but southerly wind also appears with high frequency. The mean annual rainfall is 550-600 mm, but in the last years it was less than the average so Szeged belongs to the areas of high drought sensitivity.

2.2. Structure of the city

On the basis of geographical position it is possible to divide Hungarian cities into three categories: valley, meeting point of mountainous area and plain, and plain. From the point of view of urban climate development, in the case of the first two categories it is very difficult to separate the effects of topography and human impact. Szeged belongs to the the third category, so it has favourable conditions for urban climate research. For this reason the results of systematic measurements and analysis can serve as a basis of general conclusions (*Unger et al.,* 2001).

The administrative area of Szeged is 281 km^2, but the inner city is only around 30 km^2, and the densely built-up areas are inside the flood prevention circle dike. The road structure of the city is an avenue-boulevard system on the axis of the river Tisza.

3. METHODS OF SURVEYING WORKS AND GEOINFORMATICAL MEASUREMENTS

3.1. Study area and the collection of temperature data

In the last years urban climatologic researches have been aimed at the inner parts of the city. In order to systematise the collected datasets the study area was divided into 500 m X 500 m grid-cells (*Fig. 1*). The same grid size of 0.25 km^2 was applied in some other urban climate projects (e.g. *Park,* 1986), and similar size is applied by *Long et al.* (2003) and *Lindberg et al.* (2003). The study area consists of 103+4 cells, which cover the inner and suburban part of the city. The four western cells were used just as a reference area for the comparison of temperature data. In this two-part study we used an area consisting of only 35 cells as a representative sample area (see details in *Gál et al.* (2005))

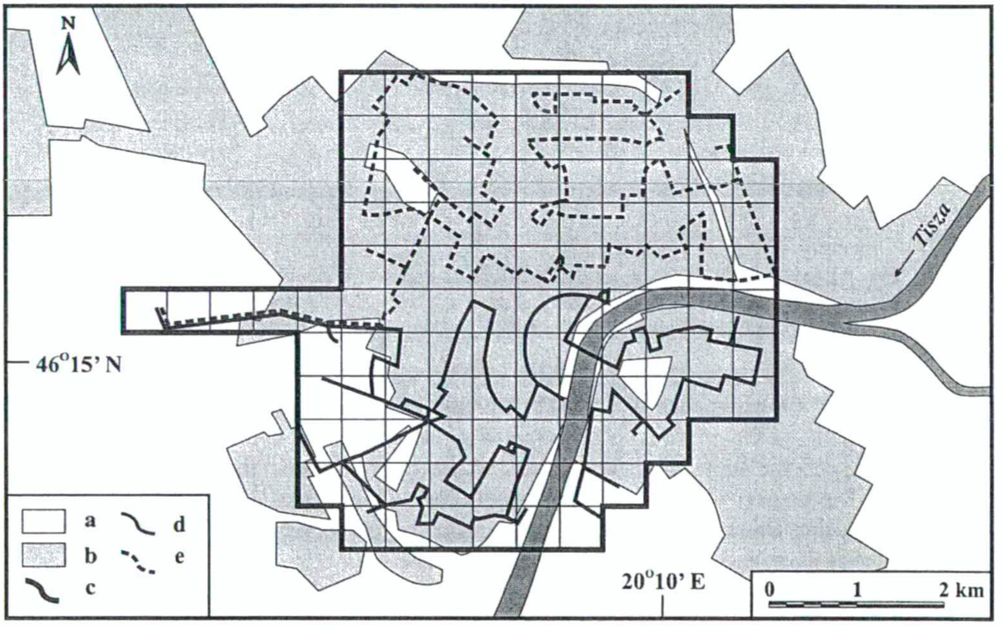

Fig. 1 The investigated area and the grid network in Szeged: (a) open area, (b) built-up area, (c) border of the investigated area, (d, e) measurement routes

Data required for the analysis of the maximum *UHI* intensity were collected in the whole (107-cell) grid network (*Fig. 1*) with measurement cars on given routes in two periods: between March 1999 and February 2000, and between April 2002 and March 2003. Such mobile measurements are wide-spread in the study of urban climate parameters (e.g. *Oke and Fuggle,* 1972; *Moreno-Garcia,* 1994; *Santos et al.,* 2003).

In the study area the representative temperature pattern was derived from measurements taken in two one-year long series every 7-10 days, so 48 and 35 times a year, respectively. The three-hour measurements were made in all weather conditions except rain. Based on experiences from previous studies data collection happened in the expected time of maximum development of the *UHI* that is at 4 hours after sunset (*Oke,* 1981; *Boruzs and Nagy,* 1999). In the hours after sunset the linear change of temperature was applied to the the calculation of the measured data, with that addition that it is only approximately valid in the suburban areas because of the the different cooling gradients (*Oke and Maxwell,* 1975).

The area was divided into two sectors because of the size of the study area and the length of measurement routes. Routes were determined to intersect all the cells at least once both there and back (*Fig. 1*). The temperature data were observed by an automatic sensor which was connected to a digital data logger. The sensor measured the values in every 10 seconds. It was placed on a bar at 0.6 m in front of the car and at 1.45 m above the ground because of the thermic disturbing effect of the car. The speed of the car was 20-30 kmh^{-1} for the sake of suitable ventilation and density of data. In compliance with this there are data from every 55-83 m along the measurement routes. At the rare stops (e.g. red light, barrier) the logged values were deleted from the database later. The measured temperature data were calculated as their average in each cell.

In our case the *UHI* intensity (ΔT) is defined as follows:

$$\Delta T = T_{cell} - T_{cell(W)}$$

where T_{cell} = temperature of the actual urban cell; $T_{cell(W)}$ = temperature of the most western rural cell (*Fig. 1*).

3.2. Determination of urban surface parameters

3.2.1. Built-up ratio, water surface and sky view factor

Determination of the built-up ratio (covered surfaces – streets, roofs, parking lots, etc.) is based on the evaluation of a SPOT XS satellite image, taken in summer 1992. The ground resolution of the pictures is 20 m, so they are suitable to determine the small-scale characteristics of the city area. The basis of the analysis was the calculation of the Normalised Difference Vegetation Index (NDVI) by raster and vector geoinformatical systems. With this index it is possible to determine the percentage of the built-up (*B*) and water surfaces (*W*) in each cell (e.g. *Unger et al.,* 2000).

Several solutions are known for the calculation of the *SVF* parameter: angular measurement by theodolite (*Szakály,* 1962), evaluation of photos taken by camera with fish-eye lens (*Oke,* 1981; *Holmer,* 1992), or the use of a software, which evaluates the 3D geometry of the surface (*Souza et al.,* 2003, 2004). In our research the approximate values of the *SVF* were determined by theodolite. Along the measurement route the elevation angles of the highest points of the buildings at both sides of streets were measured approximately every 100 m (*Unger,* 2004; *Unger et al.,* 2004).

3.2.2. Compactness parameters

The size and shape of buildings got into the focus of attention in recent urban-geometrical research and several experiments were aimed to express this by one parameter.

One of such parameters is the so-called compactness, and according to the interpretation of *Long et al.* (2003) this is the ratio between the perimeter of the building and the perimeter of a circle of the same area. This parameter is mainly emphasised because of its aerodinamical importance. This value describes a 2-dimension (2D) slice of urban geometry, but the vertical structure of the city also affects the physical conditions of the air significantly. Applying statistical methods, it was possible to indicate the connection between the *UHI* and the new 3D parameters (e.g. the building mass – *BM*), supported by geoinformatic evaluation (*Santos et al.*, 2003). Regardless of their surface the *BM* describes the buildings' volume, and the mass is calculated from the volume which can be connected to the heat-storing capacity of the given building.

Accordingly, if the connection of the surface geometry and the *UHI* is examined, it is necessary to look for a parameter more expressive then the previous one. This has to satisfy the following requirements:

- It has to describe the surface of buildings from the viewpoint of their heat emission and absorption capacity towards the ambient air.
- It has to include the volume (or mass) and thus, it should also give a value for the heat storage capacity of buildings.

Using geoinformatical evaluation methods it is possible to determine the heigths of walls (H), the area (A) and the perimeter (P), and from these the surface (S) of buildings. However, the plan area of buildings cannot be considered an active surface from the point of view of the ambient air, therefore calculating the active surface of a building (S_b) it is necessary to disregard this area:

$$S_b = P \cdot H + A$$

A given body cools slower if its surface belonging to a given volume is smaller. Similarly, a given body can store more heat if the volume belonging to a given surface is larger. Therefore, it seems more practical to take the volume/surface ratio of body into account for the creation of the new parameter. The most compact building form (cube) of settlements has to be considered a reference, because it is house-like; also among the prism-form buildings the cube has the smallest surface with a given volume (*Fig. 2*).

In the interests of comparison an approximate value was calculated for the volume of a given building, and the smaller parts of buildings and the roofs were disregarded. This geometrical simplification is possible because many flat-roofed buildings exist in the area (e.g. block-houses as well as industrial buildings, etc.) moreover the determination of the volume of more complicated forms would be practically impossible in case of thousands of buildings. The simplified volume (V_b) is calculated in the following way:

$$V_b = A \cdot H$$

Consequently, the volume (V_b) and surface (S_b) in case of a given building are available. Based on the following equation it is possible to calculate the side length (a) and thus the active surface (S_c) of a cube of the same volume (V_c):

$$V_b = V_c = a^3, \qquad S_c = 5 \cdot a^2$$

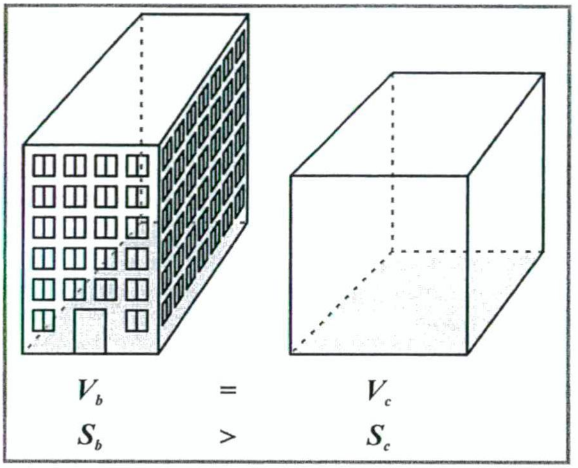

Fig. 2 Comparison of the characteristics of a building in the city and a cube; V_b, V_c, S_b and S_c mark the volume of the building, volume of the cube, surface of the building and surface of the cube, respectively

Dividing the building surface (S_b) by the cube surface (S_c), the result is a dimensionless ratio value larger than 1, which means in geometrical sense the deviation of a given body from the cube. Since the above-mentioned parameters (ΔT, B, W, SVF) were determined to cells, it is worth to apply this method in case of new parameters as well. This ratio is called *compactness* (C), and its mean by cell is called *average compactness* (C_m):

$$C = \frac{S_b}{S_c}, \qquad C_m = \frac{1}{n}\sum_{i=1}^{n} C_i$$

In each cell the number and size of the buldings are very varied and C_m is not suitable to express this. As a solution the compactness values (C) of houses are multiplied by the volume (V_b) of the house. Thus, compactness is weighted by the value of the volume, and then summarized values are calculated to all the buildings of the cell. The new parameter (C_v) is the *weighted volumetric compactness* (in m^3):

$$C_v = \sum_{i=1}^{n}(C_i \cdot V_{bi}) = \sum_{i=1}^{n}\left(\frac{S_{bi}}{S_{ci}} \cdot V_{bi}\right)$$

3.3. Geoinformatical methods and their applications

Geoinformatics is extremely suitable for the collective handling of large datasets and maps. By its application it is possible to realise measuring, processing, and demonstration of data. Digital photogrammetry is a special branch of geoinformatics. According to the definition, it is a science of image creation from an object without touching it, and the handling and processing of these images (*Barsi,* 2000). Pictures are either taken by digital cameras, or the information is stored on traditional film that is the analogue information holder and has to be digitised by scanning. During photogrammetrical processing the images are restored to the spatial position and direction valid at the time of exposure (exterior orientation). After the orientation it is possible to measure and map spatial extensions with the application of pictures taken from two different directions, similarly to human perception.

3.3.1. Applied databases, software and maps

Raster basis:

30 pieces of overlapping (60%) aerial photographs cover the city of Szeged (*Fig. 3*). The negatives were digitised by a scanner (14 micron resolution), thus the size of one photograph in TIFF format is nearly 900 Mbytes.

Important information needed for the use of aerial photographs:

- date of flight: 13th November 1992, am 11:45- pm 12:15 (highest Sun altitude),
- photograph scale: 1:11.000,
- flying altitude: 1760 m.

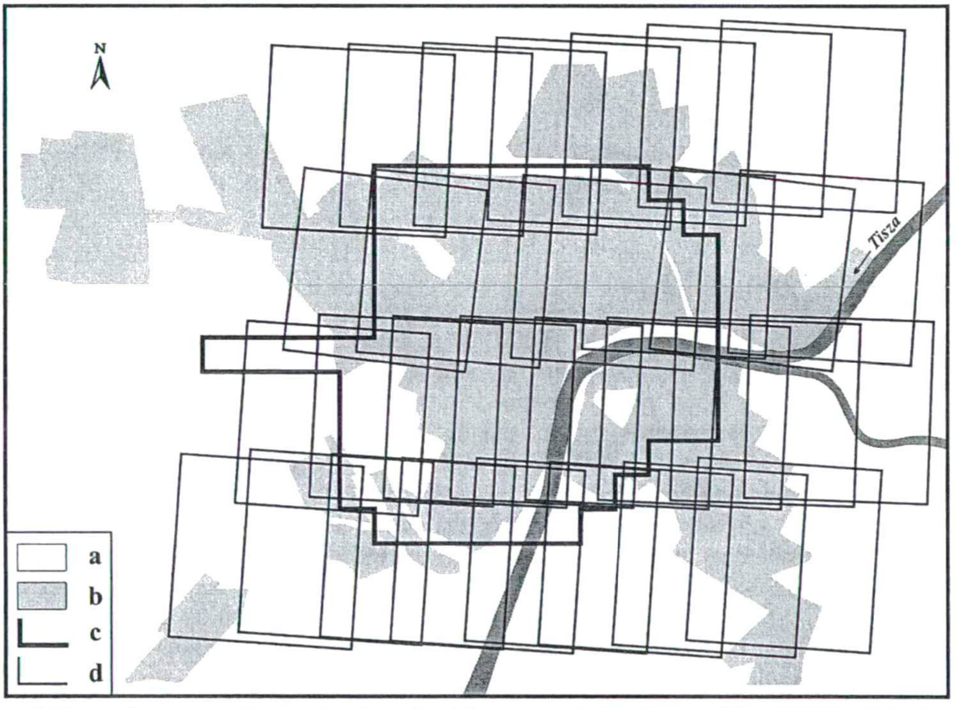

Fig. 3 The study area and the overlapping of aerial photographs on Szeged: (a) open area, (b) built-up area, (c) border of the investigated area and (d) frame of aerial photo

Accurate measuring is only possible if the digitised negatives used are of excellent quality. There is a very essential qualitative difference between the scanning of negative applied by us and the often used method of scanning of paper copies.

Vector basis:

The plan areas of buildings were available in DXF format. The mean error of the vector file is 10 cm, therefore its accuracy can be considered as geodesic.

ERDAS IMAGINE:

This software has been developed for resources research therefore with its pyramid-based data-storage and handling system it makes possible the opening, conversion and processing of large raster files (*ERDAS,* 2000). This extendable and developable software environment consists of modules and has a graphic user interface. The following modules were used in this study: OrthoBASE, Stereo Analyst and VirtualGIS.

ESRI ArcView:

The program is based on the concept of integrated georelational unified topologic data model and was made for database creating, modelling and analysis. It is a complex GIS data base environment. The main concepts of development were the open system structure (portability), the object-orientated approach (data model, user surface and applications), and the support of client-server network connections.

Xtools extension: it is developed for vector-based spatial analysis, the conversion of shape files and tabular data management.

1:10,000 scale maps:

Geodesic-topographic maps of Unified National Mapping System (in Hungarian EOTR): No. 27-323, 27-332, 27-341, 27-342, 27-343.

3.3.2. Processing

Digital Elevation Model:

The Digital Elevation Model (DEM) is a general spatial model, which means it represents a bare surface without landmarks. For the creation of the DEM it is possible to use digitised contour lines, points measured by GPS or geodesical methods, and other available elevation databases, or points can be measured by photogrammetrical means. Following data acquisition the DEM is created by the assignment of a regular grid by means of linear and non-linear algorithms.

In the case of Szeged the variation of the elevation is small (75.5–83 m a.s.l.), so using a DEM enabled us to increase accuracy (as the DEM determines the accuracy of the orthophoto). After digitising the 1:10,000 scale maps the contour lines were vectorised in ERDAS IMAGINE (Arc/Info format), then DEM of this area created by use of the Create Surface application. Later we used this DEM for the preparing of orthophotos and for the visual representation of the model in VirtualGIS.

Aerial photos (import and orthocorrection):

The ERDAS IMAGINE is able to handle lots of various data formats, like for example TIFF, BMP, PCX, LAN. In the case of TIFF files, ERDAS IMAGINE can read the GeoTIFF and the TIFF World formats as well. For further use it is necessary to transform the TIFF format into IMG format, which is the own format of ERDAS IMAGINE. During the import of files additional RRD files (containing information on the pyramid structure) are produced for each picture. With the help of this pyramid-like data storage system, the program can handle large amount of data (the size of all the aerial photos together is more than 30 GBytes).

The basis of orthocorrection is the DEM. The process involves creation of the Block File, input of the digitised aerial photos in IMG format into the Block File, calculation of Pyramid Layers, measurement of the adjusting points, aerial triangulation, the creation and quality-control of orthophotos.

Plan areas of buildings:

ArcView is able to open the plan area in DXF format, but it is also necessary to transform it into shape format. A grid of the complete study area is fitted to this basis. Buildings with an area of more than 15 m^2 were measured, since in the case of smaller (room-like) buildings the heat absorption and emission are negligible, moreover these are difficult to determine on the aerial photos.

To check this presumption, a suburban and a central cell were analysed. Results show that in the suburban area the number of buildings with an area of less than 15 m^2 is about half (51.2%) of the number of all the buildings in the cell, but it means only 4.5% of the building plan area of the complete cell. In the central cell about one-third of the buildings (37.1%) are smaller than the limit, but it means only 1.7% of the plan area of the complete cell. If the volume of these tiny buildings were calculated they would play an even more insignificant role in the cells, because of their small heights.

All buildings got an eight-digit identifier, whose first four digits show the number of the cell, and the following four digits show their serial number within the cell. To ensure easier orientation the IMG format orthophotos were laid under the plan areas of buildings. Both vector and raster data are in the Unified National Projection (EOV in Hungarian) so they exactly overlap each other (layer structure).

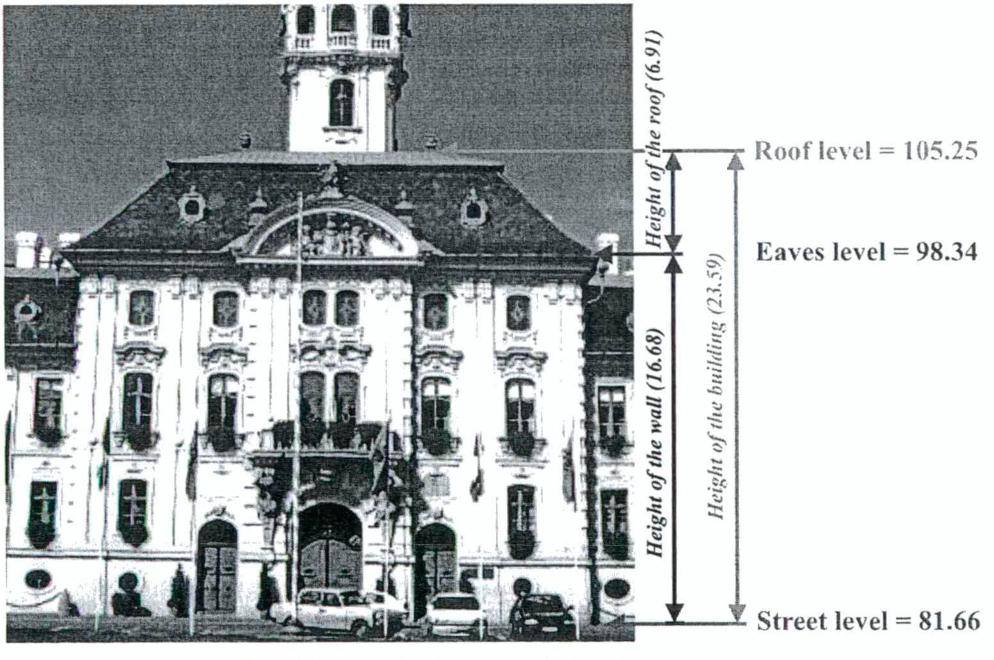

Fig. 4 Measured building data during the evaluation

3.3.3. Measurement and presentation

The 3D measurements were taken in the ERDAS IMAGINE Stereo Analyst module. There are several ways of stereo visualisation; in our case the well-known anaglif method was applied. Floating cursor was used in the measurement, which can be moved in Z direction in addition to X and Y direction. Three data were measured on all buildings: the street level, the eaves level and the roof level, and roof-types also were described with a code (*Fig. 4*).

The ERDAS IMAGINE offers many tools in the 3D visualisation. One of these is the Image Drape and with this the image can be fit perfectly on the suitable DEM in the presentation. The point of view and other parameters can be freely modified. This is a possibility to get a simplified 3D image of the building by choosing suitable elevation data (*Fig. 5*). The figure demonstrates very well the structural-morphological differences in the city. The view of picture is from the NW part of the inner city towards the NE part of the city. The higher buildings of the city centre are visible on the right side, followed by smaller ones, and finally high block houses extend in the distance.

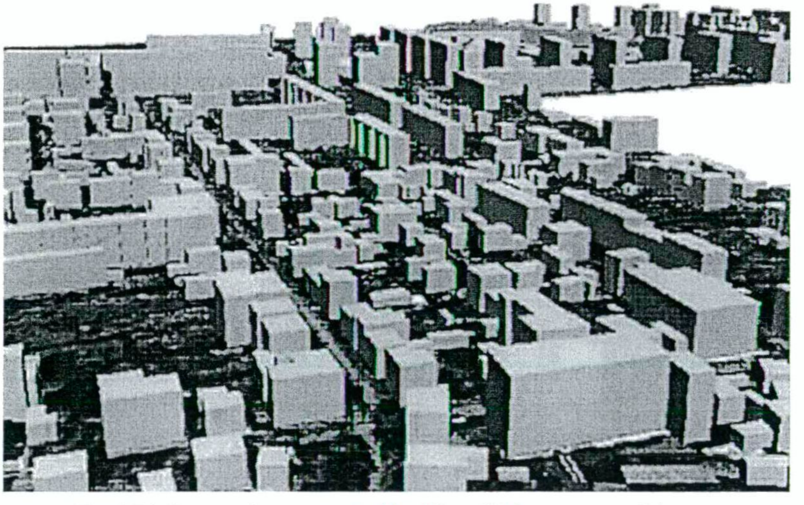

Fig. 5 Bird's-eye view generated by VirtualGIS on a part of the city

3.3.4. Update and accuracy

The newly-built large shopping centres have not existed in the aerial photos of 1992, although they have already been presented in the plan area database. Since these giant buildings with their large parking lots can significantly influence the thermal conditions of their environments, data update was important. This was done with the help of aerial photos taken on 5 August 2003 so now the surface parameters dataset is connected strongly in time to the periods of temperature measurements.

Heights data of buildings measured by ERDAS were checked by theodolite measurement in the cells at the edge of the study area. Here the error of the aerial-triangulation could be expected to be the highest but the ratio of difference of the values was 5% on average compared to the entire height of the building, and based on almost 100 element, the average deviation was not more than 58 cm.

4. FURTHER STEPS

In this article we reviewed the study area, the measured urban surface parameters and the applied methods (remote sensing, field measurements). In the next part of this article we shall describe the applied mathematical methods defining representative sampling and the structure of the statistical model (*Gál et al.*, 2005). Then we present the model created by the above-mentioned methods and its verification including possibilities of implementation and further development.

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GENETIC TYPES, HUMAN IMPACT AND PROTECTION OF HUNGARIAN KARSTS

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Összefoglalás – A magyarországi karsztoknak két típusát különböztetjük meg: az aggteleki típust és a dunántúli típust. A dunántúli típus karsztjain tektonikai mozgások hatására a mészkő és dolomit blokkokra töredezett. Ezeken a karsztokon csak néhány dolina, víznyelő található, legtípusosabb felszíni forma a karr felszín. Az aggteleki típus tektonikailag kevésbé zavart és típusos karsztformák jellemzik. Környezeti hatások szempontjából a karsztok igen érzékeny területek. A karsztos tájak átalakulása az ősember megjelenésével indult. Az ősember a tűzifát a karsztokról gyűjtötte be, s ezzel megkezdődött az erdőirtás a karsztokon. Később az emberi beavatkozás egyrészt a mezőgazdaság, másrészt az ipar révén módosította a karsztok formálódását. Két karszt terület nemzeti park hazánkban, emellett néhány karsztunk természetvédelmi terület. A Természetvédelmi Törvény (1996) a forrásokat, dolinákat, barlangokat, az endemikus flórát és faunát, valamint a biotópokat védetté nyilvánította. Megállapíthatjuk, hogy a karsztok Magyarországon többnyire védettek, de napjainkban még vannak konfliktusok a természetvédelem és a tájhasználat között.

Abstract – There are two major types of Hungarian karsts: Transdanubian type and Aggtelek type. The Transdanubian type consists of those karsts that were significantly affected by tectonic movements and they are faulted into blocks of limestone and dolomite. Surface features in these karsts are scarce, only a few dolines and gorges are present, and karrenfields are the most typical features. The Aggtelek type karsts are tectonically less disturbed and usually characterized by typical karst features. From an environmental point of view, karsts belong to the most sensitive areas. Landscape transformation in the karst environment started with the appearance of early humans. Early man gathered firewood from the karsts, thus the deforestation of karst regions began. Later human activity modified karst formation due to agricultural activity on the one hand and by industry on the other. In Hungary two karst areas (Bükk- and Aggtelek Mts.) have been designated as national parks, and some are nature reserves. The Law on the Protection of Nature (1996) declared all the springs, dolines, caves, endemic flora and fauna protected. We can say that the karst areas of Hungary are mostly under protection but we still have some conflicts between nature protection and landuse on the karsts.

Key words: Hungarian karsts, genetic types of karsts, human impact on karsts, protection of karsts

INTRODUCTION

Hungary is situated in the central part of the Carpathian basin, surrounded by the Alp- Carpathian and the Dinaric mountain chains. Its area is 93,030 km^2. Its karst area is small, only 1.45% of the country's territory (1350 km^2). The climate is moderately continental, more precisely a transition between oceanic and continental climates. Sunshine duration is 1700-2100 hours; the annual average temperature varies between 8-11 °C. The annual precipitation is higher in the western regions (6-800 mm) than in the eastern parts

(5-600 mm). The main wind direction is northwest-southeast, but in the east north-eastern winds are common as well.

The characteristics of Hungary's geomorphology are determined by the Mesozoic karst blocks of the Transdanubian Mountain Ranges, the volcanic ranges of the Northern Mountain Ranges and the submerging basins of the Great and Small Plains. The general course of Hungarian Middle Mountain Ranges follows a southwest-northeast axis, the average height of the mountain ranges is below 1000 m. The geomorphologic characteristics of the country were further modified by Quaternary sediments, present in most areas.

The vegetation of Hungary, (the pannon flora domain), belongs to the Middle-European flora territory in the holarctic flora empire. The natural vegetation of the mountains consists of deciduous forests (Quercus, Fagus), while those of the forested steppe in the plains are either grasslands (on loess, sand or lick) or oaken (Quercus robur) groves. Only 15 % of the country's area is covered with natural vegetation.

In the above-mentioned environment the karst areas of Hungary are isolated patches within masses composed of volcanic rocks or sandstone. The tectonic and hydrological environments are varied; the karsts have diverse morphostructures (*Jakucs,* 1977).

Generally we can say that the karst areas of Hungary are mostly protected. Besides the different environmental factors man changes the natural condition of karsts.

DISCUSSION

Geomorphology evolution of Hungarian karsts

In the Palaeozoic and Mesozoic era the massif Tisia, remainder of the Variscides, was situated where now the Carpathian basin lies. Nowadays only isolated patches of this massif can be found on the surface in Hungary. During the Mesozoic era the sea Tethys covered it; the limestone and dolomite of the Transdanubian and Northern Mountain Ranges are of Triassic origin. The western parts of Mecsek Mountains also consist of Triassic limestone while the limestone in the eastern parts is of Jurassic origin.

By the end of the Mesozoic era, today's Transdanubian Mountain Range became part of the mainland. As a consequence of weathering in a subtropical climate karst bauxit formed on the limestone and dolomite, which was covered by marine sediments later, during the Cenozoic era. In the upper Tertiary period the area of the Carpathian basin was still a mainland of average height. During the lower Tertiary period the surrounding mountains began to emerge and the basin was formed. On the margins of the basin, along the faults, Europe's most intense volcanic activity took place. This activity resulted in the formation of the volcanic ranges of Börzsöny, Cserhát, Mátra and Zemplén Mountains. In the end of the Tertiary period the Pannon Sea covered the area of Hungary and that's when today's Great Plain submerged and the crystalline base became covered with marine sediment to a depth of 2-3000 m. When the sea was gone the pannon sediments were overlain by fluvial sediments of several hundred m depth. In Transdanubia and at the pediment of the mountains the pannon sediments formed hills. After the retreat of the Pannon Sea, the mountain ranges rose a further 2-400 m and their rise is continuous even today.

Genetic types of Hungarian karsts

Most of Hungary's karst areas are situated in the Transdanubian Mountain Ranges (*Fig.1*). They mostly consist of Mesozoic (especially Triassic) limestones and dolomites. The members of the Transdanubian Mountain Ranges in order from southwest are the Keszthelyi Mts (dolomite), the eastern area of Balaton hills (Mesozoic dolomite karsts), the Bakony Mts (Triassic limestone and dolomite karsts), the Vértes Mts (Triassic dolomite), Mt Gerecse (Triassic limestone karsts), Mt Pilis (Triassic limestone karsts) and the Budai Mts (hydrothermal karsts) with the Tétényi plateau (Sarmatian limestone).

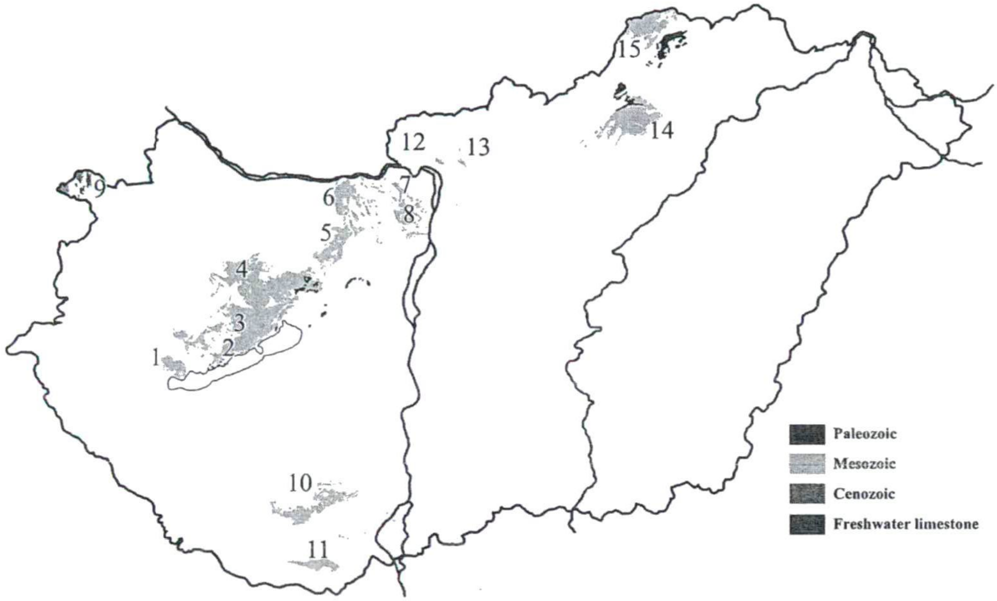

Fig. 1 Location of Hungarian karsts

1.Keszthely Mts., 2. Balaton Highland., 3. Southern Bakony Mts., 4. Northern Bakony Mts., 5. Vértes Mts., 6. Region of Gerecse Mts., 7. Pilis Mts., 8. Buda Mts., 9. Lajta Hills of Fertőrákos., 10. Mecsek Mts., 11 Villány Mts., 12. Szokolya Basin and Törökmező in the Börzsöny Mts., 13. Naszály, Romhány Mt. Csővár Mt. in the Region of Cserhát Mts.

In the Northern Mountain Ranges a few smaller limestone patches (Lajta limestone in South-Börzsöny, and the smaller blocks in Cserhát Mountains: Mounts Naszály, Romhányi and Csővári) can be found as foot hills of the main volcanic range. Karst areas in the Bükk and Aggtelek Mountains consist of Triassic limestone and dolomite.

Isolated karst blocks similar to the latter are situated in the south-eastern parts of Transdanubia: the Mecsek and Villány Mountains with the karst block of Beremend (Triassic and Jurassic limestone karsts), there's also an isolated patch in Transdanubia's north-western corner, at Fertőrákos (Lajta limestone)

Karst areas in Hungary are varied in terms of their geological composition, tectonics, landscape evolution and geomorphology (features both above and under the surface) alike. There are two major genetic types defined on the basis of the factors above: Transdanubian type and Aggtelek type.

The Transdanubian type consists of those karsts that were significantly affected by tectonic movements (like all those in the Transdanubian Mountain Range) and they are faulted into blocks of limestone and dolomite. Surface features in these karsts are scarce, only a few dolines, sinkholes and gorges are present, and karrenfields are the most typical features. They are rich in caves and features formed by hydrothermal activity. Traces of the karstification that occurred on the border of the Cretaceous and the Paleocene were preserved under the coal and bauxite deposites.

The Aggtelek type karsts are tectonically less disturbed and usually characterized by typical karst features. They abound in both surface and underground features, their typical features include karrenfields, solution dolines and dry valleys. Caves (sinkhole caves, spring caves, through caves) are common. Karst areas of the Bükk, the Aggtelek-Rudabánya Mts and the western parts of the Mecsek Mts. belong to that type.

In Hungary's karst areas Triassic and Jurassic limestones are the most common rock types. The Triassic, Jurassic and Cretaceous limestones and dolomites of the sea Tethys can be found in both the Northern and Transdanubian Mountain Ranges, also in the Mecsek and Villányi Mts. These rocks are ideal for carstification and allow the formation of a rich variety of karst features.

Caves are important part of Hungary's natural resources. At the beginning of the 20th century, 200 caves were listed, while at the end of the century, 1314 were known. Nowadays, due to the increased interest in discovery research, 3700 caves are registered by the Institute of Speleology (*Székely,* 2003). Most of these can be found in the Bükk and Bakony Mts. There are 29 caves longer than 1 km, while 99 exceed 200 m in length. Longest of them is the Baradla cave in Aggtelek (25 km together with the Domica cave in Slovakia). The connection between Pálvölgyi and Mátyáshegyi caves in the Budai Mts. was revealed only in 2001, and together they form the second longest cave in Hungary (19 km). The third one, (the Béke cave in Aggtelek) is 7.2 km long. The deepest of the caves, the Istvánlápai cave can be found in the Bükk Mts, with a depth of 250 m.

Hungarian karsts are mostly residual karsts (*Jakucs*, 1977); the traces of earlier karstification are clearly noticeable in several places. Tectonic activity affected the formation of both surface and underground features. Hydrothermal phenomena are common. The most significant thermal water activity with cave and mineral formation, also specific surface rock features occurs mostly on Triassic dolomite and limestone, especially in the Budai and Keszthelyi Mts., also in Miskolc-Tapolca, situated in the foreground of the Bükk Mts. Hydrothermal activity with cave and mineral formation, sometimes also with special surface rock features, occurs especially on Triassic dolomite and limestone. These formations are the hydrothermal caves, dolomite powder, siliceous rock towers, pinnacles, travertines. The surface karst formations are the round karren with root karren, which are exposed at the surface. Typical bare karrenfields occur in Aggtelek and Villány Mnts., but similar formations can be found in the Transdanubian Mts. at Veszprém, Hajmáskér, Várpalota and Budaörs. On the Aggtelek type of karst occur the solution dolines. These features are primarily situated in formerly river valleys or on plateau surface as individual dolines. Erosional karst valleys and different cave systems are the results of erosion processes. These formations occur both in the Transdanubian and Aggtelek type karsts.

Human impact on karst in Hungary

From an environmental point of view, karsts belong to the most sensitive areas. Due to its open hydrological system and 3-dimensional reaction surface a karst area reacts very fast to anthropogenic activity.

Both fossil and recent karst features occur on Hungarian karsts. During the latest phase of karstification, landscape transformation in the karst environment started with the appearance of early humans. In the Middle and Upper Pleistocene prehistoric man used caves in Hungary. Early man gathered firewood from the karsts, thus the deforestation of karst regions began. Later human activity modified karst formation by agriculture on one hand and by industry on the other. Agricultural activity was intensive in Aggtelek and Villány Mountains at the turn of the century. For this reason soil erosion was so widespread that rock solution decreased. At the same time the microclimate and vegetation were also modified. With industrialisation and the beginning of mining, the undesired ground waters were pumped out.

In some of my previous studies, I have already introduced the model which summarises the connections of the karst ecological system (*Bárány-Kevei 1998a, 1998b*). Connected to this model, I study those factors and processes, which are relevant from the point of all the processes of the landscape changes in any karst environment. The climate-soil-vegetation system has crucial importance from the point of view of karst dynamism. The changes of these factors influence the intensity and tendency of the landscape change processes. The environmental problems in the Hungarian karsts are the following:

- In the karst region of Transdanubia bauxite mining resulted in the decrease of the karst water table from the '50s until the '90s.
- Industrial and agricultural pollution damaged the karst, which provides a very important drinking water supply in the mountain regions.
- The degradation phenomena of Aggtelek karst can be related to earlier agricultural use. At the same time the grazing demand of the settlements also exceeds the necessary extent.
- Agricultural and industrial use of the karst results in the soils being contaminated by heavy metals.
- Acidification of soils causes dripstone re-dissolution in some caves.
- In the Bükk Mountains forest management caused some places to develop extreme microclimate, which makes forest regeneration more difficult.
- Quarrying processes damage some Hungarian karsts.

The combinations of the above-mentioned processes prevail in a number of sites. The primary objective of this study is to point out the fact that environmental factors directly and indirectly affect the environment-sensitive karsts via different spheres of the karst system and these often disrupt the balance of the whole system. For this reason their research has been carried out in a complex manner; knowing the mutual effects of the processes it is possible to make suggestions for the planning.

The protection of Hungarian karsts

In Hungary, the Law on the Protection of Nature, which came into force in 1996, declares that "in karst areas, all the springs with a yield more than 5 l/min, all the dolines, caves, all endemic flora and fauna and their biotopes are under protection". Consequently in these areas all intervention changing the natural ecological state should be avoided.

Two karst areas have been designated as national parks (*Fig.2*), the first of them, Bükki National Park in 1976. Aggteleki National Park came into being in 1985. Together with the caves of the Slovakian karst, it is a UNESCO World Heritage site. In the national parks all the geological features, caves, springs, waters, natural flora and fauna are under strict protection.

In addition to these two national parks, there are several nature reserves, like the Gerecsei, Pilisi and Vértesi which include certain strictly protected areas.

In Hungary there are 29 caves longer than 1 km, while 99 exceed 200 m in length. Longest of them is the Baradla cave in Aggtelek (25 km together with the Domica cave in Slovakia). The connection between Pálvölgyi and Mátyáshegyi caves in the Budai Mts. was revealed only in 2001, and together they form the second longest cave in Hungary (19 km). The third one, (the Béke cave in Aggtelek) is 7.2 km long. The deepest of the caves, the Istvánlápai cave can be found in the Bükk Mts, with a depth of 250 m.

In European standards, the protection of karst areas and caves is very advanced in Hungary, due to the Law on the Protection of Nature and the Ministry of Environment Protection, which operates the Institute of Speleology to ensure high-level karst protection.

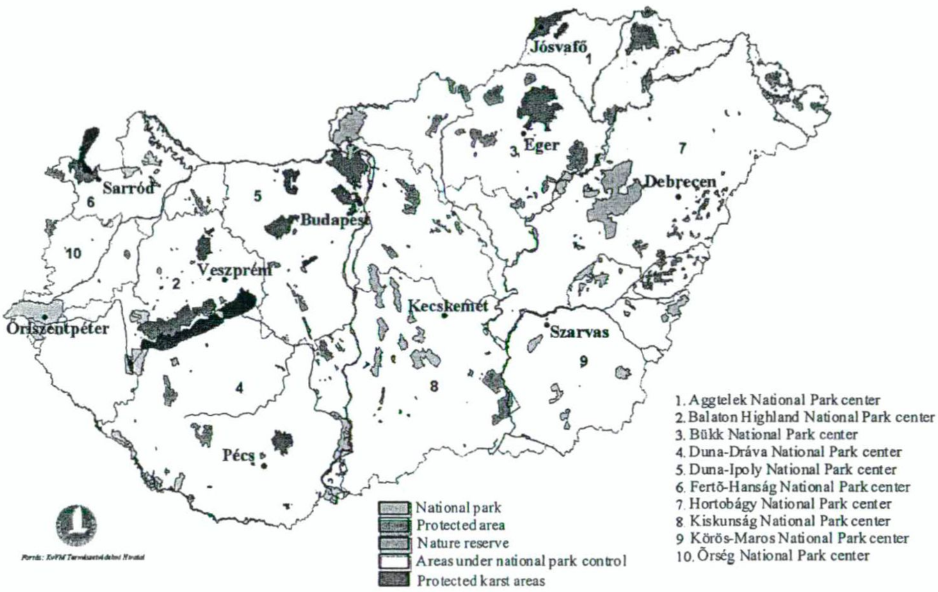

Fig 2. Protected areas of Hungary

CONCLUSION

(i) There are two major genetic types of Hungarian Karsts: Transdanubian type and Aggtelek type. Two karst areas (Bükk- and Aggtelek Mts.) have been designated as national parks, and some are nature reserves. Early man gathered firewood from the karsts, thus the deforestation of karst regions be gan. Later human activity modified karst formation by agriculture on one hand and by industry on the other.

(ii) The environmental factors directly and indirectly affect the environment-sensitive karsts via different spheres of the karst system and these often disrupt the balance of the whole system.

(iii) Generally we can say that the karst areas of Hungary are mostly protected. Besides the different environmental factors man changes the natural condition of karsts.

(iv) In the future we have a duty to manage the conflict between nature protection and landuse.

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MAPPING THE URBAN GREEN AREA INFLUENCE ON LOCAL CLIMATE UNDER WINDLESS AND LIGHT WIND CONDITIONS. THE CASE OF WESTERN PART OF ATHENS, GREECE.

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Összefoglalás – A vizsgálatok a városi zöldterületek lokális klímamódosító hatására irányultak. Éjszakai mobil mérések történtek szélcsendes és enyhe széllel jellemzett időjárási körülmények között Athén termikusan terhelt nyugati részén. Erre a célra három különböző méretű és jellegű zöld terület került kiválasztásra. Az észlelt adatok feldolgozása egy GIS szoftverrel történt. Az eredmények szerint a léghőmérsélet és a számított Diszkomfort Index területi szerkezete a zöld és a beépítetlen területek enyhítő hatását igazolták.

Summary - Investigations concentrated on the influence of the urban green areas on the local climate. Nocturnal mobile measurements were carried out under windless and light wind conditions, over the thermally polluted western part of Athens, Greece. For this purpose three green areas with different size and characteristics were selected. The collected data were analysed using geographical information system software. The spatial patterns of air temperature and the calculation of Discomfort Index indicated a beneficial influence of green areas and non built-up areas.

Key words: urban green areas, mobile measurements, Athens, Greece

INTRODUCTION

In most European countries as well as in Japan, there is a strong interest about results and information on applied urban climatology, which can be incorporated into urban planning processes (*Matzarakis and Mayer*, 2003). Athens is a European capital which has grown fast in the last four decades. This growth causes a rise of thermal and chemical pollution. The western part of Athens is densely built-up and includes residential and industrial regions. This, in relation to narrow roads and heavy traffic burden has resulted in discomfort due to environmental conditions for the city residents. Over this area, an intense urban heat island is observed. This phenomenon is mitigated by the sparse urban green of this area (*Chronopoulou et al.*, 2004).

This study is focused on three vegetated areas in the thermally polluted area of the western part of Athens. In order to evaluate the qualitative and quantitative influence of those green areas, mobile measurements were carried out under stable meteorological conditions.

STUDY AREA AND METHODS

In the western part of Athens, Greece, overpopulation and the consequent intense constructing of large buildings has led to the lack of open spaces of considerable size that could be used for the development of parks and recreation sites. The study area covers almost 11 km^2 and includes a wide range of land uses. The larger green areas included are the Campus of Agricultural University of Athens (A.U.A., almost 0.34 km^2, marked with A), two urban parks (0.026 km^2 and 0.006 km^2, marked with C) and a public cemetery (almost 0.29 km^2, marked with B). The topographic relief of the area is almost planar. The residential regions are placed in the SE and NW. The industrial area is almost continual from the NE to the SW of the study area (*Fig. 1*).

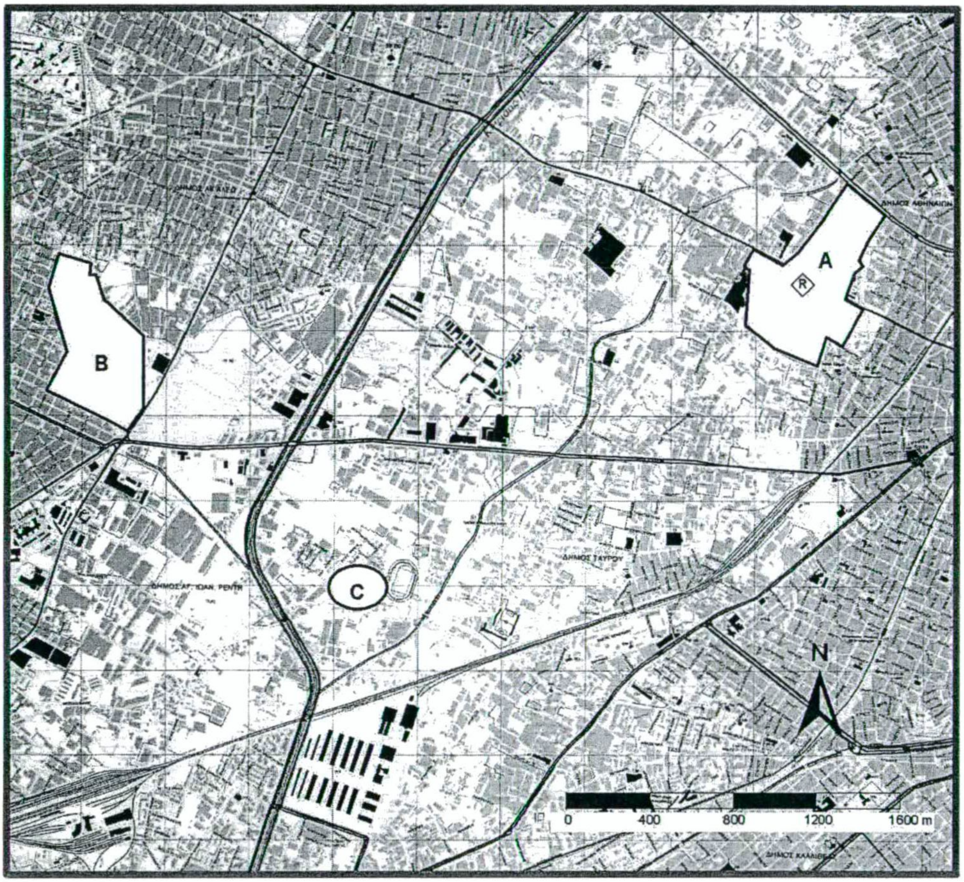

Fig. 1 The study area: A - The campus of Agricultural University of Athens, B - Public cemetery, C - Couple of bioclimatic designed parks, R - Reference point

In order to investigate the influence of the urban green areas on the local climate, a number of nocturnal mobile measurements were carried out over the study area during the period of April 2000 to October 2001. The survey was conducted by automobile vehicle equipped with meteorological instruments, data logger and a portable personal computer (PC). The parameters which were measured on each sample point were air temperature, relative humidity, wind speed and wind direction. All the data were sampled at 1.8 m height above the ground under dry anticyclon weather conditions when clear skies and light wind were reported. Those data were recorded in the portable PC for further statistical and geostatistical analysis.

In order to scan the study area, preliminary measurements in a sparse sampling network were taken. A multi-focused, dense sampling network was designed using those measurements. The survey was focused on the major green areas, the built-up areas and every area causing variation on the spatial pattern of air temperature and relative humidity. A total of 61 sampling points were located in the network. In order to collect the data, a double loop route (*Kuttler,* 1993) was performed passing through all sampling points. The measurements lasted less than 3 hours, starting at 23:00.

The collected data were separated in two major classes in relation to the wind speed. The first class contains data that were collected under windless conditions (< 1 ms^{-1}) and the second one contains data that were collected under light wind conditions (< 3.5 ms^{-1}). In order to make time-based corrections, data from the meteorological station of A.U.A was used. The time-corrected data from every nocturnal route were inserted in geostatistical software to produce rasters via Kriging method (*Cressie,* 1993) that illustrate the spatial pattern of the parameter (air temperature and relative humidity). A map of average air temperature and relative humidity of each class was produced by using the same software. In addition, Discomfort Index was calculated combining air temperature and relative humidity spatial patterns under windless conditions. Finally, spatial calculations were used to evaluate the qualitative and quantitative influence of the major green areas on the local climate.

RESULTS AND DISCUSSION

The results based on 7320 field measurements over 60 routes showed that the wind speed has significant influence on air temperature variation. Green areas and non built-up areas had better thermal conditions compared to the industrial and residential areas. Those beneficial conditions exist in both case studies of windless and light wind conditions (*Potchter et al.,* 1999). For the illustration of more comprehensive results, the maps represent the temperature difference between every point and the coldest point over the study area (marked with R). The coldest point under both case study conditions was recorded inside the campus of A.U.A. Every temperature value which is reported in this study refers to this difference.

Fig. 2 illustrates the map of average air temperature under windless conditions. The temperature range was beyond 5.4°C. Low temperature values were recorded over area A which is the largest green area over the measurements field. This area is covered with evergreen and deciduous trees, shrubs and frequently irrigated grass. The buildings are of medium height and sparsely built. The cooling influence of area A expands more than a half kilometre to the Southwest where the buildings are sparsely placed. Area B is found to be cooler than its surroundings, but it is less influential than area A and C. The temperature contours seem to connect the green areas A, B and C and the less densely built-up areas forming a hemicyclic sector of lower temperature values. The less built-up areas are parallel to the railways and the temperature difference over them reaches 2.8°C. On the other hand, area C which includes two urban parks has significant influence on the thermal spatial pattern despite the fact that it is the smallest in size. The beneficial influence of this area is probably caused by the bioclimatic design of those parks. They are planted with shrubs and trees and there are small artificial water bodies inside. Finally, area B is warmer than the reference point (A.U.A campus) and significantly cooler than the neighbouring residential areas.

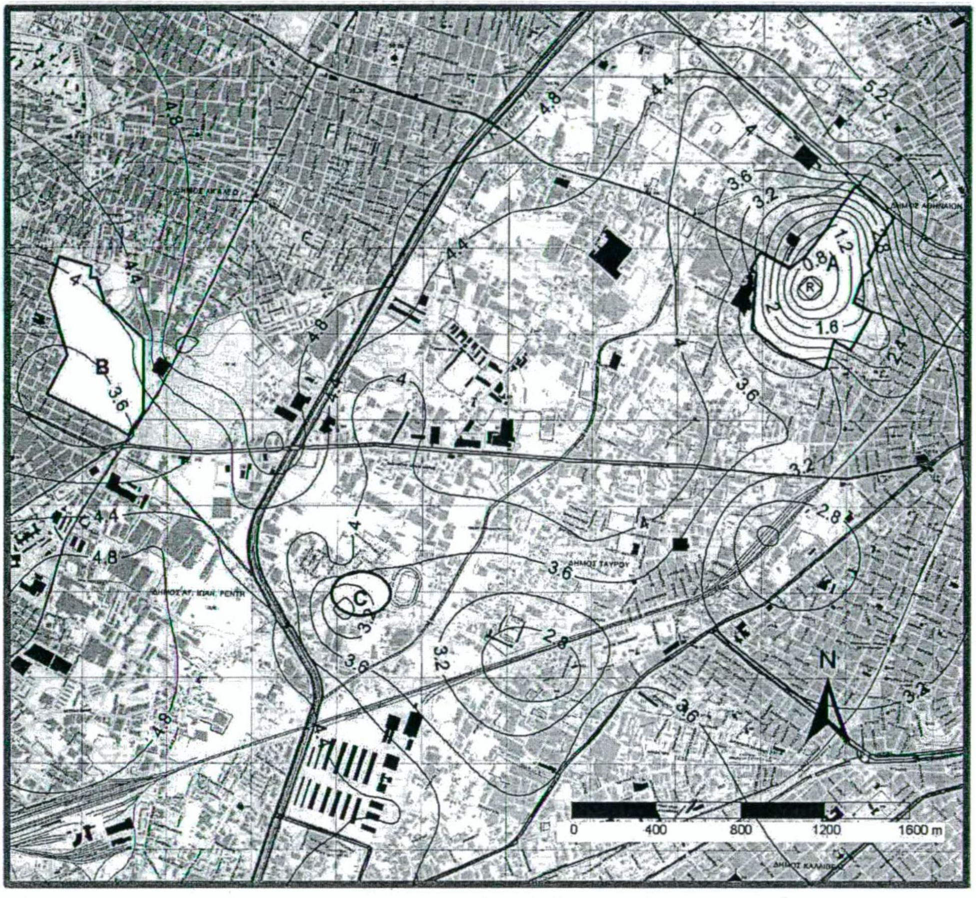

Fig. 2 Spatial pattern of mean air temperature under windless conditions (<1 ms^{-1}). Reference point temperature: 25.7°C.

We can assume that the green areas in this case study look like cool spots in a thermally polluted region. Table 1 contains the percent of the study area related to the temperature difference from the reference point, under windless conditions. Focusing on these results, it is obvious that less than 5% of the study area differs less than 2.8°C from the reference point temperature. Combining the results of *Table 1* and the spatial pattern in *Fig. 2* it is obvious that the three vegetated areas remain the coolest regions of the study area. They can also affect the thermal conditions of the neighbouring areas. This effect is less significant if the area is built-up, especially if it is a residential area. In the spatial patterns (*Figs 2 and 3*) the residential areas are darker and the industrial are light-coloured. The latter are located in the middle of the map. In the northern part of area A the cooling influence seems to be intercepted from the narrow urban canyons and the densely populated area. The same climatic function occurred north and south of area B. Moreover this residential area has narrow urban canyons and dense population.

Table 1 Percentage of study area surface related to air temperature under windless conditions.

Temperature difference under windless conditions (°C)	Surface, % of the study area
0-0.4	0.05
0.41-0.8	0.19
0.81-1.2	0.33
1.21-1.6	0.36
1.61-2.0	0.49
2.1-2.4	0.62
2.5-2.8	2.79
2.9-3.2	8.84
3.3-3.6	13.42
3.7-4.0	15.09
4.1-4.4	18.41
4.5-4.8	18.17
4.9-5.2	19.53
5.3-5.6	1.71

As expected, under light wind conditions the spatial temperature variation is lower than under windless conditions (*Fig. 3*). The temperature range is almost 1.5°C. The study area seems to be thermally homogenous despite its intense complexity. A, B and C areas seem to be cooler compared to the whole area. The spatial temperature formation under those conditions is similar to the formation caused by windless conditions. The cooler hemicyclic sector exists, but it is less intense.

Table 2 contains the percent of the study area related to the temperature difference from the reference point, under light wind conditions. Combining the temperature spatial pattern in *Fig. 3* and results of *Table 2*, the influence of green and non built-up areas is obvious. As expected, the densely built-up and industrial areas are significantly warmer than the green and non-built areas.

In order to evaluate the bioclimatic comfort the spatial pattern of the Discomfort Index (DI) was calculated. Generally DI took values between 23.2 and 25.6°C under windless conditions. DI values were found less than 24°C only inside and around area A. The value of 24°C is critical because below this less than 50% of the population feels discomfort and beyond this more than 50% of the population lives under discomfort conditions (*Unger*, 1999). Close to area C the DI took values between 24 and 24.4°C. According to these results, the influence of the green areas is beneficial to the bioclimate of the whole region.

It is obvious that urban green areas have an important role on nocturnal cooling processes (*Landsberg,* 1981). Despite the fact that green areas cover only 6% of the study area, they seem to have a strong influence on local climate. The temperature variation is much smaller under light wind conditions but the green areas' influence remains significant. In order to have more detailed knowledge of the bioclimatological conditions related to vegetated areas, more specific surveys should be designed. Additional measurements of radiation and other geographical factors would give a better view of the study area functions (*Unger*, 2004).

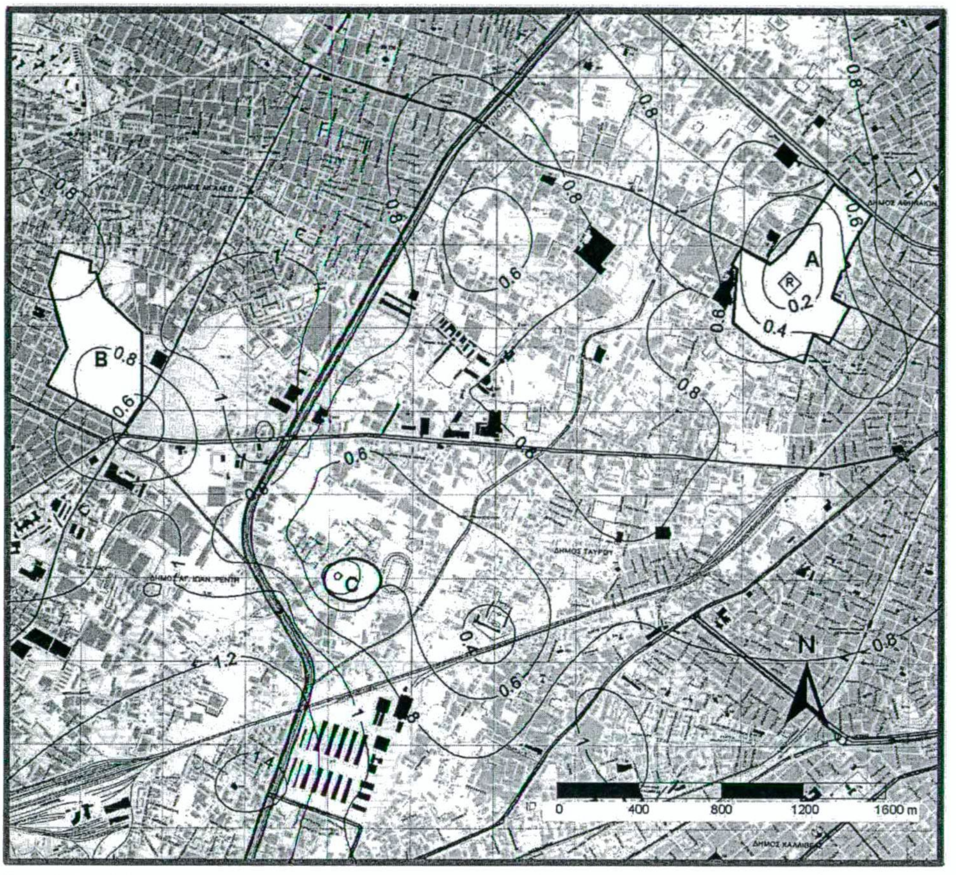

Fig. 3 Spatial pattern of mean air temperature under light wind conditions (< 3.5 ms^{-1}). Reference point temperature: 25.3°C.

Table 2 Percentage of study area surface related to air temperature under light wind conditions

Temperature difference under light wind conditions. (°C)	**Surface, % of the study area**
0-0.2	0.5
0.21-0.4	1.68
0.41-0.6	7.69
0.61-0.8	30.64
0.81-1.0	43.81
1.01-1.2	9.37
1.21-1.4	5.91
1.41-1.6	0.4

According to the results of mobile nocturnal surveys, the need for more urban green areas became obvious (*Moriyama and Matsumoto,* 1988). The state and the related ministry should encourage the extension of bioclimatic designed parks. Finally those parks should be established in close proximity to each other so as to strongly mitigate the thermal pollution.

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LANDSCAPE ECOLOGICAL RESEARCHES IN THE WESTERN MAROSSZÖG (HUNGARY)

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Összefoglalás – A Maroszög részletes élőhely térképezése 2002-ben kezdődött. A munka első lépéseként 2002-ben elkészítettem a vizsgált terület első 1:50.000-es aktuális élőhelytérképét a CORINE-CÉT (CLC-CÉT) élőhelyosztályzó rendszer szerint. A 2004-től induló MÉTA program (Magyarországi Élőhelytérkép Adatbázis) során az élőhelyek természetességét, regenerációs potenciálját, veszélyeztető tényezőit is térképeztük. Emellett a talaj és növényzet kapcsolatának vizsgálata is hangsúlyos szerepet kapott a vizsgálatban. A vizsgálati terület 4 részre különül el élőhely-kompozíció alapján. Ezek a Tisza-Maros-szöge, a Torontál, a Maros és a Tisza Marostorok körüli szakasza, valamint a Maros felsőbb (magyarországi) szakasza (Landori-erdő Nagylak közöt). A felszíni üledékek, a talajok, a másodlagos szikesedés hatása, a folyók dinamikája és a tájhasználat hatása az élőhelyekben visszatükröződik. Az élőhely-kompozíciók természetessége és az ökorégiók kvantitatív növényföldrajzi analízise alapján a táj agrár-urbánus táj, sok természet közeli, értékes élőhellyel, amelyek regenerációs potenciálja jónak mondható.

Summary - The detailed landscape biotope-mapping of Marosszög (Marosangle) has begun in 2002. As thc first step of this work I made the first 1:50,000 actual vegetation map of the study area in 2002 on the basis of the CORINE-CÉT (CLC-CÉT) habitat classifying system. The naturalness, the regeneration potential, the risk factors were also mapped during the Hungarian Biotope-Map Database (MÉTA) programme started in 2004. Besides these factors the study of the connection between soil and vegetation played an important role in the research. The research area has 4 characteristical parts according to the biotope composition which are the Tisza-Maros szöge (Tisza-Maros-angle), Torontál, Lower Maros and Tisza river section around the mouth, and the upper Hungarian Maros river section between Landori-forest and Nagylak. The effects of the surface sediments, soils, secondary salinization, flood dynamics and land use are summarized in the habitat-types. The naturalness of the biotope-compositions and the quantitative plant geographical analysis of the ecoregions show that this is an agricultural-urban landscape with a lot of near-natural valuable biotopes with good regeneration potential.

Key words: landscape ecology, biotope mapping, connection between soil and vegetation, flood-area and alcali sodic habitats, naturalness, regeneration potential, ecoregion

INTRODUCTION

The study area is situated in the Southern Tiszántúl of Hungary between the settlements Szeged-Makó-Hódmezővásárhely. Dominantly it is part of the Marosszög microregion, but the most nothern part of the study area is streching into the South Tisza Valley microregion. Both belong to the Lower Tisza Region (*Marosi and Somogyi*, 1990). The area is covered by alluvial sediments. The common geomorphological features of this landscape are the abandoned early Holocene riverbeds and belt-banks of river Maros and Tisza which enclose flood-free loess-silt areas, but only in Torontal and alongside the eastern border of Maroszug.

Marosszög is bordered in the northeast by the Pleistocene loess-land of the Csongrádian Plain (Hódmezővásárhely-Batida-Makó-Nagylak-lane). This curvy borderline fits to the 80 m elevation contour line. The western border of this region is the South-Tisza-valley. This landscape continues towards Serbia-Montenegro and Romania. The Marosszög connects to the Lower Maros Valley at Nagylak and Sejtény in the southeast. The southern border of Marosszög could be the line of Krstur (Ókeresztúr) – Banatsko Aranđelevo (Oroszlámos) – Beba Veche (Óbéba) – Cenad (Nagycsanád).

Soil geographical studies on the Szegedian part of this study area were published by *Keveiné Bárány* (1988), who used the categories of Géczy. *Takács* (1989) presented a genetic soil map of Csongrád County according to the TIM code system (Information System of Protection and Monitoring of Soils, RISSAC).

A transboundary comparing work studied the river Maros in 1991, which collected soil, hydrological, floristic (vascular plants, phytoplancton) and faunistic (zooplankton, shells, arthropoda, fishes, birds) data (*Sárkány-Kiss et al.*, 1997). The former and recent geographical and biological researches of the Maros valley between Szeged and Makó were reviewed by *Gaskó* (1999). This work describes the history of the landscape and the geographical names; it also presents microclimatical examinations, vegetation, protected plants, the condition of the forests and zoological researches (Cerambycida, Coleoptera, fish, amphibia, reptiles, birds and mammals).

The examined landscapes belong to the Crisicum flora district of the Eupannonicum flora area which is part of the Pannonicum flora province (*Marosi and Somogyi*, 1990). The few coenological maps made of this region only have historical value, as the landscape has changed since then. Maps were made at the mouth of the Maros (*Bodrogközy*, 1971), and at the Beach and Nagylegelő (Great Pasture) of Makó (*Tóth*, 1967). In 2002 I created a 1:50,000 digital CLC-CÉT biotope map for the area situated between Szeged, Makó and Hódmezővásárhely. In 2004 the researches became more intensive and covered almost the whole Southeastern Csongrád County.

METHODS

The genetic soil maps of TIM- (*Takács*, 1989) and Géczy's system were suitable to examine the connections between soil and vegetation (*Keveiné Bárány*, 1988).

The vegetation was classified according to the CORINE-based systems (CORINE biotope map (CÉT) (*Molnár*, 2000), CORINE Land Cover (CLC) (CLC50) (*FÖMI*, 2000)) biotope category-systems are used for biotope maping. The use of both the CLC and CÉT is required, because the CLC is too general for natural or semi-natural habitats but the CÉT includes categories only for natural and semi-natural biotopes. On the presented map some categories (mainly urban and agricultural biotopes) are integrated *(Fig. 1)*.

The base maps of the biotope maps are the 1:25,000 and 1:50,000 Gauss-Krüger topographical maps (*MH*, 1992). The State Forestry Service's forest management plans (*ÁESZ*, 1998a) and maps (*ÁESZ*, 1998b) helped to identify the forest biotopes. All the information of the different maps is digitised with ArcView GIS 3.2. with the help of SPOT-4 satellite images (*CNES*, 1998). I used the naturalness and the ecoregion of biotopes for quantitative analysis. The naturalness was classified according to Németh-Seregélyes on a scale of 1 to 5 (*Molnár*, 2003). The naturalness and the regeneration potential can be integrated in one concept called ecoregion (5-level scale) (*Bölöni et al.*, 2003; *Molnár*, 2003). The Habitat Guide (*Bölöni et al.*, 2003) contains definitions and describes the naturalness and regeneration potential for each biotope.

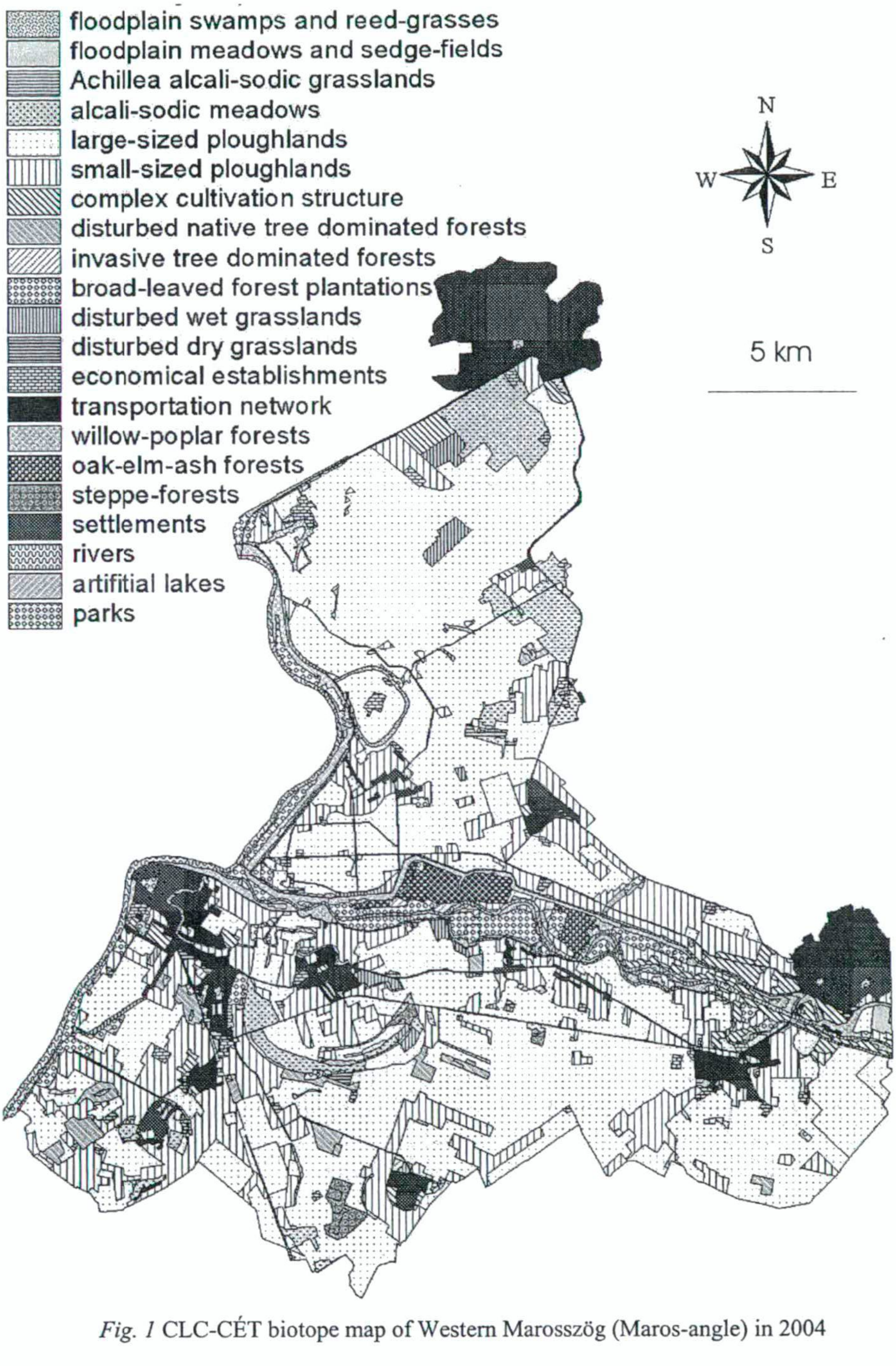

Fig. 1 CLC-CÉT biotope map of Western Marosszög (Maros-angle) in 2004

RESULTS AND DISCUSSION

Floodplain region between the Landori-forest and Makó (Upper Maros Section)

The soil of the area between the dykes is soil deposit (according to Géczy's classification or humic meadow alluvial soil (according to TIM). The floods appear here regulary. Their duration and height influence the vegetation. In these areas the biotope diversity is higher than the genetical soil diversity *(Table 1)*. The biotope diversity grows further because of the land use (e.g. on the place of the willow-poplar forests flood-areal meadows can be formed in case of mowing or grazing).

The Upper Maros Section has higher habitat diversity. This part is a mixture of traditional floodplain agricultural, natural and semi-natural floodplain habitats. The natural and semi-natural biotope components are the reeds, the floodplain meadows, the willow-poplar forests, the oak-elm-ash forests and the sand bank vegetation. The reason of higher biodiversity could be the greater role of natural landscape formation as it is a border area between Hungary and Romania. Intensive land use was not so common here.

The changing of the riverbed is quite intensive in this section. The formation of islands and sandbanks is very typical, especially between Apátfalva and Nagylak. I discovered 2 new islands between Ferencszállás and Kiszombor. The succession of these islands is very fast. Within a few years the Nanocyperion community changes into a Salix alba-dominated gallery forest. The Salix-shrubs are not long-lasting.

The river Maros and its dykes accompanied by willow-poplar forests with good naturalness. The riverside patches are in better condition. Some of them are old; the majority of them are middle-aged. Unfortunately, invasive species attacked them: Amorpha fruticosa, Fraxinus pennsylvanica are the most frequent, but Acer negundo, Vitis riparia, Echinocystis lobata, Xanthium italicum also appears. However, they are not as common as in the Tisza-valley.

Oak-elm-ash forests are quite rare and can be only seen at Makó. Their naturalness is rather medium. Some of these forests are transitions towards willow-poplar forests. This forest type is almost extinct in the Great Hungarian Plain, and it is much rarer alongside the river Tisza. The patches at Makó are threatened by being built in.

Table 1 Connection between soil and vegetation in the floodplain between the dykes in Western Marosszög

Soils		**Vegetation**	
Genetical map (TIM-code)	**Géczy's map (*Keveiné Bárány*, 1988)**	**mm-ÁNÉR (GNHS)**	**CORINE Biotope map (CÉT)**
- humic meadow alluvial soil (39/5)	- soil deposit	A1. reed-grass of eutrophic standing waters B1A. non-peaty reeds, bulrushes, rushes D34. meadows J4. willow-poplar floodplain forests J6. Hard-wooden floodplain forests	115. Open water-surface with reed-grass 111. floodplain swamps 121. floodplain meadows and sedgefields 212. willow-poplar forests 224. hard-wooden oak-(elm-ash) forests

Floodplain meadows can be found almost only in this upper river section. These meadows were pastures and hay-fields earlier, but they are not always used the way like in the past as the number of the farm animals is decreasing. Their naturalness is between medium and good.

The agricultural biotopes consist of very small and diverse mosaics of small-field ploughlands, abandoned, extensively used floodplain orchards, week-end gardens, old and young fallows. There are cultivated poplar-forests too, which contain a lot of invasive Amorpha fruticosa. These forests should be replaced by native poplar and willow species.

The abandoned, extensive small-sized orchards are rich in local cultivated species (plum, apple, pear, cherry, sour cherry, nut, apricot and peach). They are planted mixedly so within one little plot 20-30 different kinds of fruit species can be found. These orchards are cultural and agricultural heritage too. The big flood of 1970 destroyed the majority of them. Since then they are getting abandoned and attacked by invasive species (Vitis riparia, Fraxinus pennsylvanica, Amorpha fruticosa).

Besides the orchards a lot of ploughlands are abandoned. As these fallows are not grazed or mown they (now weedy wet grasslands) are getting filled with invasive species (Xanthium italicum, Amorpha fruticosa, Fraxinus pennsylvanica) soon and their regeneration towards floodplain meadows stops.

Floodplain between Szeged and the Landori-forest of Makó

The lower section of the river Maros and the Tisza river section between Algyő and Szeged differ in several aspects.

Forests are the most common biotopes of this river section. It is here that the naturalness of the forests alongside the Hungarian section. In Vetyehát and in the Landori-forest of Makó oak-elm-ash forests and willow-poplar forests can be found with mainly good or medium naturalness. The invasive species (Fraxinus pennsylvanica, Acer negundo, Amorpha fruticosa) are present too. The regeneration potential of these forests is medium even in the case of the oak-elm-ash forests. The main tree species (Quercus robur, Ulmus minor, Fraxinus angustifolia ssp. pannonica) are regenerating even in the willow-poplar forests, which indicate drying-out processes probably due to the deepening river-bed.

The more natural forests are situated alongside the dykes and river-banks while the area between them is filled with cultivated poplar plantations (e.g. Hajdovai-forest at Klárafalva).

The floodplain meadows, ploughlands and the orchards are almost absent. Many of them were substituted with cultivated poplar forests especially during the 1960s and 1970s, but this process still continous.

The rare oxbow lakes have ruderal plant communities (at Vetyehát) or Bolboschoenus maritimus dominated non-sodic swamp associations in their litoral zone (at Ferencszállás). Island formation is very rare.

Alongside the river Maros sand-mining is a risk factor for the natural forests. In the dried-out mines willow-poplar forests could regenerate (see at Makó), but nowadays these areas are partly built in with weekend houses.

The Torontalian landscape

The southern part of the study area is named Torontál. It is the lowest-lying region of Hungary (the lowest pont is at Tiszasziget (76 m)).

Several settlements (Serbian, Hungarian, German) were established here after the destruction of the medieval settlement system during the Turkish times: Szőreg (now part of Szeged), Újszentiván (Novi Sentivan), Tiszasziget, Deszk (Deska), Kübekháza (Kubekhausen), Klárafalva, Ferencszállás, Kiszombor.

The middle (core) part of Torontál (Szőreg-Kübekháza-Tiszasziget triangle) where pleistocene loess, infusional-loess and loess-silt deposits are dominant is covered by solonetzic meadow chernozem soils. Approaching the rivers firstly carbonated alluvial meadow soil then humic meadow alluvial soil appears on the belt-banks. The deepest parts, the abandoned former river-beds are covered by callous solonetz soil and solonetzic meadow soils (TIM-system, *Takács*, 1989).

Géczy's map shows similar distribution. The areas covered with solonetzic meadow chernozem soil are indicated to have chernozem soil on loess or alluvium, which are gradually replaced by meadow soil and soil deposit towards the rivers of Tisza and Maros. The solonetzic meadow soil areas are named in this system meadow soil with alcali subsoil of alluvial origin, the callous solonetz patches are identified as cultivated alcali soil areas (*Keveiné Bárány*, 1988).

As this area has good-quality soils, all the old forests were cut down and many of the grasslands were ploughed up. Now the landscape is dominated by ploughlands.

The vegetation of the solonetzic meadow chernozem soil, the humic meadow alluvial soil and the less productive solonetzic meadow soil mostly disappeared. The vegetation of the carbonated alluvial meadow soil remained only in the inland water-covered former riverbeds. The vegetation of the callous solonetz areas survived the human impact better.

Table 2 Connection between geomorphology, soil and vegetation in Torontál

Geomorphology	**Soils**		**Vegetation**	
	Genetical map (TIM-code)	**Géczy's map (*Keveiné Bárány*, 1988)**	**mm-ÁNÉR (GNHS)**	**CORINE Biotope map (CÉT)**
pleistocen loess, infusional-loess and loess-silt covered elevations	- solonetzic meadow chernozem soil (20/5)	chernozem soil on alluvium	F3. Aster (Aster punctatus)-Hog's fennel (Peucedanum officinale) – meadow-steppe M3 Alcali-sodic oak-forests	132. Alcali-sodic meadows 245. Steppe-forests
		chernozem soil on loess	H5A. steppe-grasslands on bound soils M2 Loessy oak-forests	144. steppe-grasslands 245. Steppe-forests
Belt-banks of the former flood-area	- humic meadow alluvial soil (39/5)	-soil deposit	F2. Alcali-sodic meadows (few alcali-sodic species) F3. Aster (Aster punctatus)-Hog's fennel (Peucedanum officinale) – meadow-steppe L5. Closed Pendunculate Oak (Quercus robur) forests (just potencial!)	132. Alcali-sodic meadows (few alcali-sodic species) 224. Hard-wooden oak- forests (just potential!)
	- carbonated alluvial meadow soil (31/1)	- meadow soil		
Abandoned river-beds of the former flood area	- callous solonetz soil (24/1)	-cultivated alcali soil	F2. Alcali-sodic meadows F4. Puccinellia alcali-sodic capes M3 Alcali-sodic oak-forests	132. Alcali-sodic meadows 245. Steppe-forests
	- solonetzic meadow soil (29/1)	- meadow soil with alkali subsoil of alluvial origin		
	- carbonated alluvial meadow soil (31/1)	- meadow soil		

The connection between geomorphology, soil and vegetation is shown in *Table 2*. Interestingly the grasslands and forests of the solonetzic meadow chernozem soils are separated according to the material of the subsoil, so Géczy's map explains the vegetational pattern better. The chernozem soil on loess has loess-steppe-grassland whereas the chernozem soil on alluvium has Aster punctatus-Peucedanum officinale (Aster-Hog's fennel) meadow-steppe vegetation. The forest vegetation may have been loessy oak-forest on chernozem soil on loess whereas alcali-sodic oak-forest on chernozem soil on alluvium.

The belt-bank–abandoned riverbed geomorphological complex has great soil diversity, but the biotopes don't always show that diversity. Both geomorphological forms are dominated by alcali-sodic meadows. On belt-banks meadow-steppe, in former river-beds Puccinellia alcali-sodic capes could appear too, but they are not frequent. More occurrences of Aster punctatus-meadow-steppe were observed in the surroundings of Ferencszállás (the edge of the road nr. 43 between Ferencszállás and Kiszombor, alongside the Szeged-Mezőhegyes railway).

The loess-steppe-grasslands are very rare; they can be found mainly at the frontier of Serbia-Montenegro-Hungary, Romania-Hungary with good naturalness.

In Torontál the Quercus robur – the original dominant tree of this land – was planted in higher proportion. The regeneration of the open alcali-sodic oak-forest and loess-steppe oak-forest can be observed at Tálagyi-forest or at Ferencszállás. The more natural forests are planted on former grasslands.

The alcali-sodic meadows are partly secondary ones and could form after the regulation of the riverways. The dominant grass is Alopecurus pratensis. Agrostis stalonifera is absent (this species is typical in this biotope in the alcali-sodic depressions of the loess-lands outside the floodplains of the Tiszántúl). Alcali sodic species indicate that this is now alcali-sodic grassland: interestingly, Limonium gmellini is not so common, but Cerastium dubium, Trifolium angulatum, Ranunculus pedatus, Podospermum canum are frequent. Little Achillea alcali-sodic grassland patches can be observed on the dried-out meadows.

Big alcali-sodic meadows are in Tataribara and Fertály in Tiszasziget and in the Szőregian-Deszkian-pasture. The Szőregian-Deszkian-pasture is the biggest grassland of Torontál and it's now a NATURA 2000 (SAC) site. In the middle of it little Artemisia alcali-sodic grassland patches appear, the only representatives of this habitat in Torontál. Unfortunately the eastern half of the pasture was ploughed up after the compensation. This is the most common risk factor at these habitats.

The Tisza-Maros-szöge (Tisza-Maros-angle) region

The triangle-shaped Tisza-Maros-szöge was a huge floodplain swamp with floodplain meadows on their belt-banks according to the 1st military survey (*HMT*, 1764-1787; *Deák*, 2004). After the regulation of the riverways the swamps dried out into floodplain meadows (*HMT*, 1806-1869). Swamps remained only in the deepest parts, but during the 20th century they were drained. The only swamps and reed-grass biotopes were preserved in the Oxbow lake of Nagyfa. During the last 100 years the majority of the meadows were ploughed up (*HMT*, 1872-1887), but the area became secondarily salinic. On the most salinic eastern edge of this landscape a chain of alcali-sodic meadows exists. These are the Nagysziget of Hódmezővásárhely and the 4 remaining patches of the Batida-puszta (previously it may have been one grassland).

Presently the Tisza-Maros-szöge is dominated by large-sized ploughlands. The area of the small-sized ploughlands hasn't grown much after the compensation. The area of forest plantations is very limited and they are dominated by non-native species. Just 2 bigger penduculate oak (Quercus robur) plantations occur on grasslands at Batida, which are regenerating slowly towards alcali-sodic oak-forest. The channels preserve the former vegetation of floodplains.

The major nature conservation values of these landscapes are the alcali-sodic grasslands. They differ in several aspects from the alcali-sodic grasslands of Torontál and the Csongrádian Plain. Their biotope-composition is dominated by alcali-sodic meadows and Achillea alcali-sodic grasslands. Their genetical soil-type differs somewhat from the Torontálian ones too *(Table 3)*.

Table 3 Connection between geomorphology, soil and vegetation in Tisza-Maros-szöge

Geolmorphology	**Soils**		**Vegetation**	
	Genetical map (TIM-code)	**Géczy's map (*Keveiné Bárány*, 1988)**	**mm-ÁNÉR (GNHS)**	**CORINE Biotope map (CÉT)**
Higher elevation belt-banks of the former flood-area	- strongly solonetzic meadow soil (29/2)	-conditionally cultivated alcali soils	F1b. Achillea alcali-sodic grasslands M3. Alcali-sodic oak-forests	131. Achillea-Artemisia alcali-sodic grasslands 245. Steppe-forests
Lower elevation belt-banks of the former flood-area	- carbonated alluvial meadow soil (31/1)	- meadow soil of alluvial origin	F1b. Achillea alcali-sodic grasslands F2. Alcali-sodic meadows (few alcali-sodic species) M3. Alcali-sodic oak-forests	131. Achillea-Artemisia alcali-sodic grasslands 132. Alcali-sodic meadows (few alcali-sodic species) 245. Steppe-forests
Abandoned riverbeds of the former flood area	- callous solonetz soil (24/1)	-cultivated alcali soil	F2. Alcali-sodic meadows M3. Alcali-sodic oak-forests	132. Alcali-sodic meadows 245. Steppe-forests
	- carbonated alluvial meadow soil (31/1)	- meadow soil of alluvial origin		

These alcali-sodic grasslands mirror the geomorphological forms: the abandoned riverbeds are dominated by alcali-sodic meadows and have callous solonetz soils or carbonated alluvial meadow soils (according to TIM). The earlier can be fit with the cultivated alcali soil whereas the latter with the meadow soil of alluvial origin in Géczy's system.

The low elevation elder belt-banks are covered with the mixture of two biotopes: mainly the alcali-sodic meadow forms matrix and the Achillea alcali-sodic grasslands appear as „small islands" in it. Their soil is usually the carbonated alluvial meadow soil (TIM) (meadow soil of alluvial origin at Géczy). On callous meadow solonetz (24/1), mid meadow solonetz (24/2), deep meadow solonetz (24/3) (*Becker*, 1991) at Nagysziget a similar biotope-combination can also be observed.

The higher elevation belt-banks have strongly solonetzic meadow soil (TIM) (conditionally cultivated alcali soil at Géczy) with Achillea alcali-sodic grasslands.

These alcali-sodic meadows are dominated by Alopecurus pratensis (Agrostis stalonifera is absent) too.

Only one secondary regenerating meadow-steppe was found at Gorzsa on a fallow, so this biotope is not typical for this landscape either. The Puccineleia alcali-sodic cape and blind alcali-sodic vegetation appears just as the result of human activity (treading) like at the former military area of Nagysziget, Hódmezővásárhely. No mappable patch of Artemisia alcali-sodic grasslands was observed.

Quantitative plant geographical analysis

Fig. 2 shows the areal percentage of the biotopes. The whole mapped 503.115 km^2 study area is basically an agricultural-urban landscape.

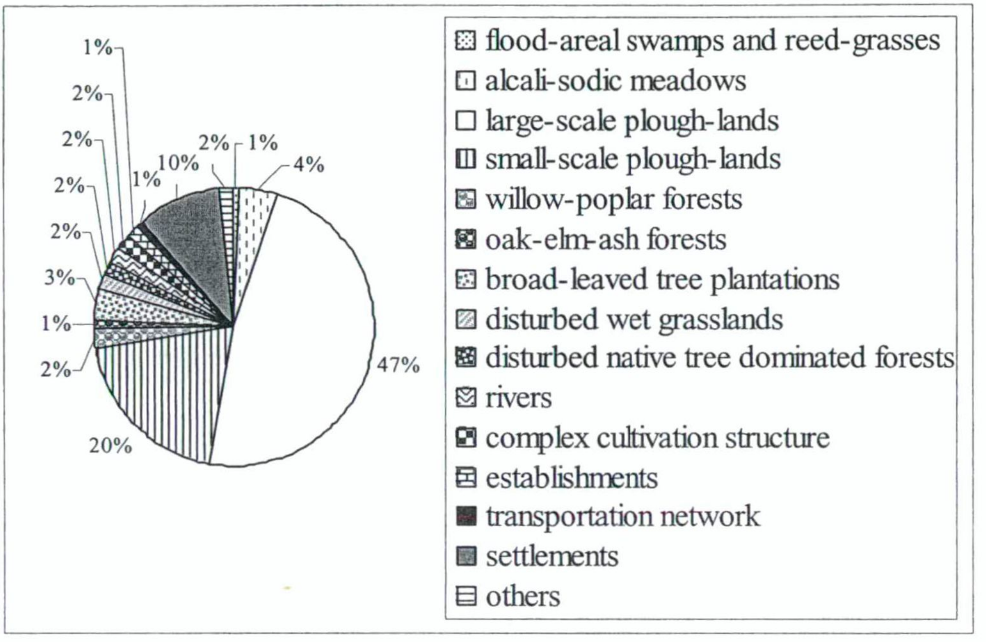

Fig. 2 Ratio of the present biotopes in the study area

67% of the area is ploughland, 10% is settlement. The biggest natural vegetation types are the alcali-sodic meadows (4%, 21.882 km^2). The rivers (7.992 km^2) and the willow-poplar (12.11 km^2) forests represent 2%, whereas the oak-elm-ash forests (5.799 km^2) and flood-areal swamps and reed-grasses (3.237 km^2) just 1% even though that they are typical parts of the riverside natural vegetion. The percentage of the broad-leaved forest plantations (17.532 km^2) which include non-native tree dominated forests is the same as the natural floodplain forests (3%). The disturbed native tree dominated forests (planted oak and native poplar forests outside the area protected by the dykes) represent 2% which is welcome (7.597 km^2).

The map of the naturalness of Western Marosszög (Marosangle) is shown in *Fig. 3*, the percentage of the naturalness of the biotopes is presented in *Fig. 4*. The majority of the study area has bad naturalness (85%, 429.357 km^2 (1) - urban and agricultural areas, non-native tree dominated forests are included here), but the 2nd biggest group is the category of biotopes with good naturalness (7%, 33.348 km^2 (4)). This category covers the majority of the willow-poplar forests and alcali-sodic meadows. 2% is given to medium-weak (8.773 km^2), good-medium (8.290 km^2) and excellent-good (9.827 km^2) transitional categories. Excellent-good is the Szőregian-pasture, the mid part of Batida-puszta and the riverbed of Maros. Good-medium category covers mainly the oak-elm-ash forests and some willow-poplar forests. Medium-weaks are the native tree dominated slowly regenerating planted forests, and some old fallows regenerating towards alcali-sodic meadow.

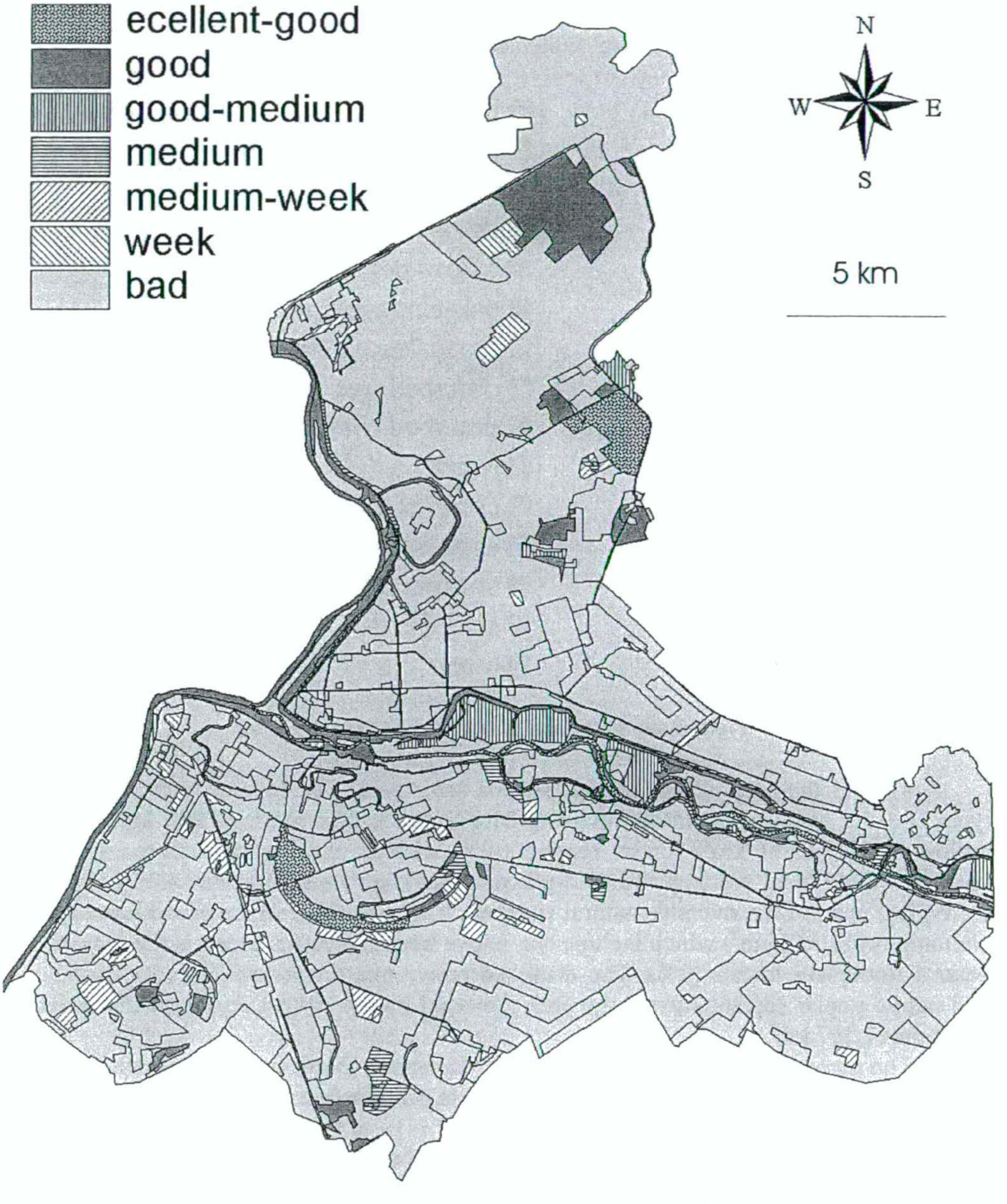

Fig. 3 Map of the naturalness of Western Marosszög (Maros-angle) in 2004

The percentages of the biotopes in the ecoregion are shown in *Fig. 5*, their map is presented in *Fig. 6*. The ecoregional classification helps landscape planning, provides spatial qualitative and quantitative data for environmentally friendly rural development and nature conservation management.

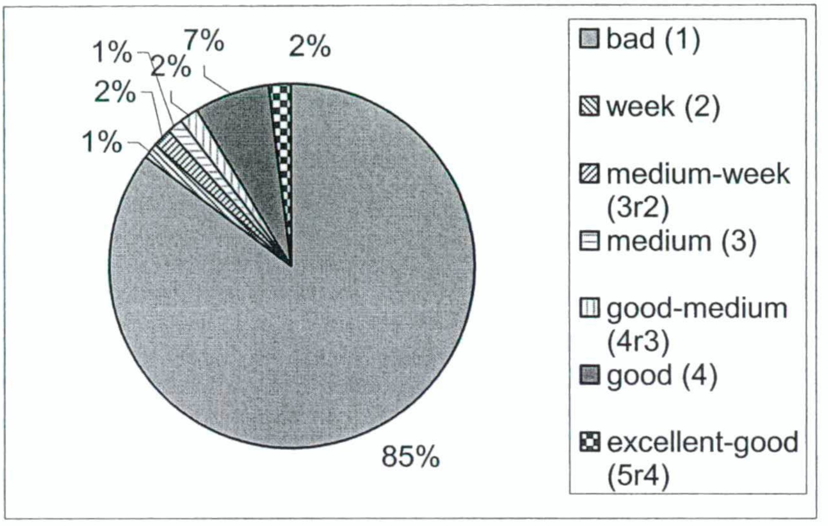

Fig. 4 Naturalness of the study area

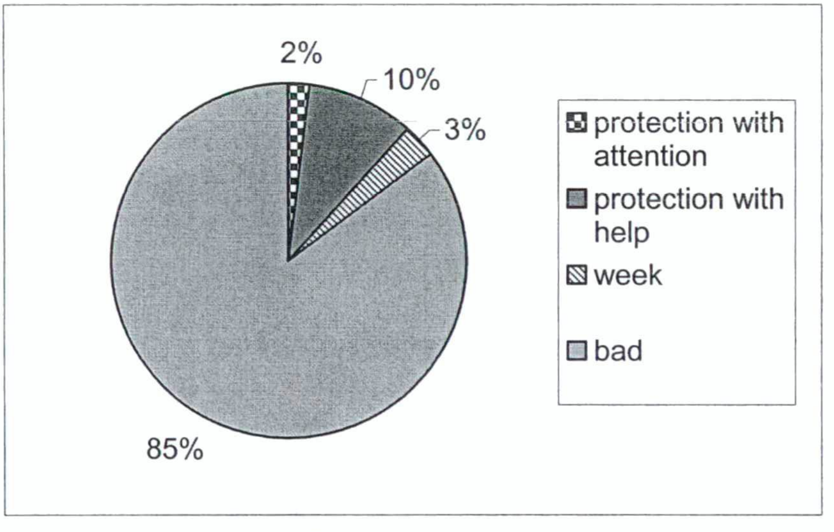

Fig. 5 Ecoregions of the study area

85% of the biotopes have bad ecoregion value (429.357 km^2: urban and agricultural areas, non-native tree dominated forests). 10% (49.155 km^2) of the area requires protection with help which means their naturalness is good or medium, and their regeneration potential is good too. Willow-poplar forests, oak-elm-ash forests, alcali-sodic meadows, Achillea alcali-sodic grasslands, regenerating disturbed grasslands (fallows on alcali-sodic or alluvial deposit), flood areal meadows and regenerating near-natural pendunculate oak plantations on alcali-sodic soils can be mentioned at this group. In these biotopes the good naturalness can be held on or achieved with adequate nature conservation management.

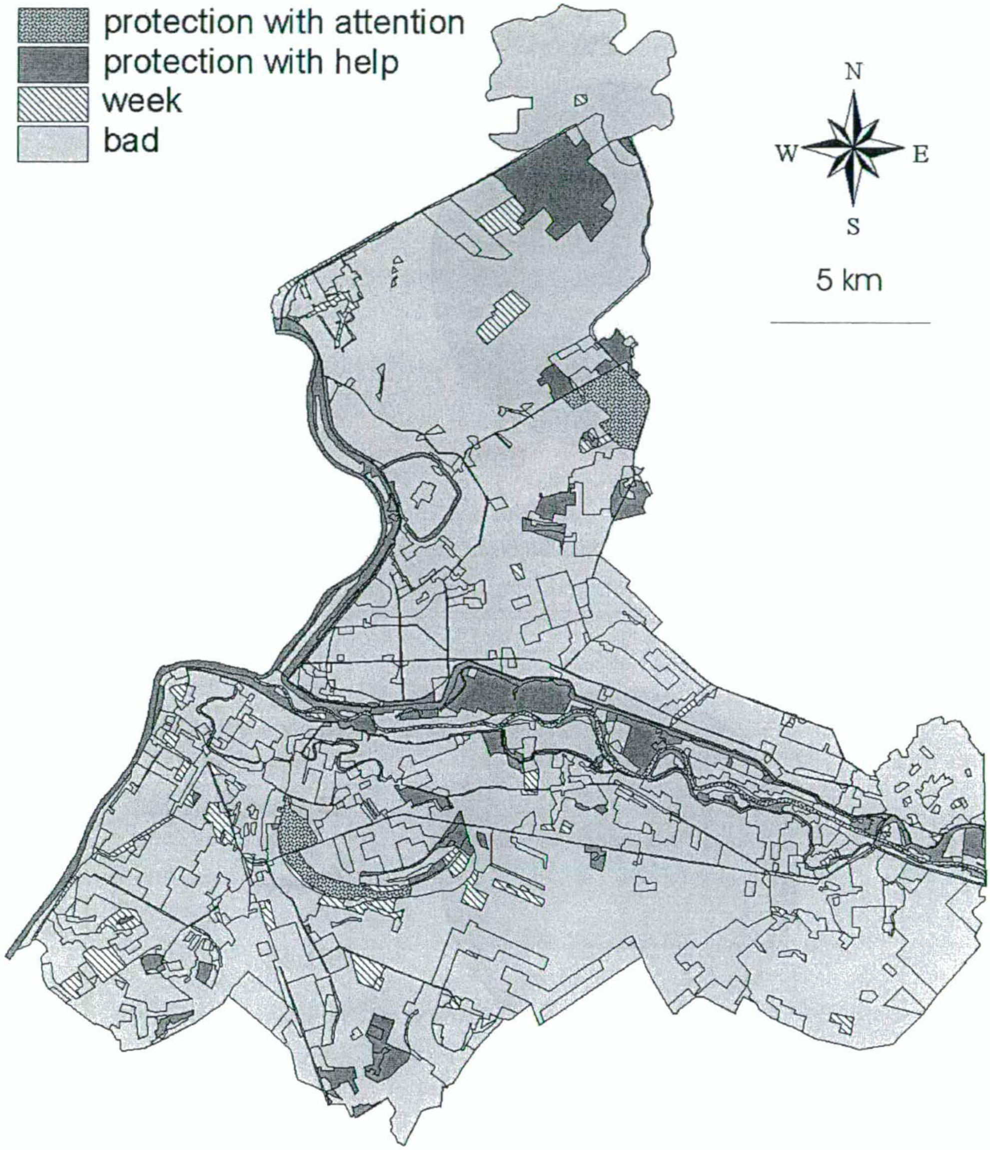

Fig. 6 Ecoregional map of Western Marosszög (Maros-angle) in 2004

Protection with attention (naturalness good-medium, regeneration potential is good) category is 2 % (9.827 km^2). The management of these areas requires special attention, as their quality is the best among the other patches; intensive human land use could destroy them.

3% (14.774 km^2) of the study area has low ecoregion value. Their naturalness is weak or medium-weak too, the regeneration processes are slow. Nature conservation management is only efficient in the long term, but the results are quite questionable. Some fallows and the slowly regenerating native tree dominated forests belong here.

CONCLUSIONS

These mapping works are good for nature conservation to get a full picture of the present conditions of the landscape. They can be a database for the monitoring and planning the landscape and are good for purposes of rural development, forest and water management. They show the regional potential of rural ecotourism and help environmental education. They help the scientific experts, the policy-makers and land-users to make optimal decisions and establish a really sustainable land use.

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GEOECOLOGICAL MAPPING IN A KIS-SÁRRÉT STUDY AREA

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Összefoglalás: Napjaink tájkutatásának fő célja megvizsgálni, hogy egy adott terület hasznosítási típusa mennyire felel meg a táji adottságoknak és milyen társadalmi tevékenység helyezhető el a legkisebb kockázattal a tájban. Az ember, mint meghatározó tájalkotó tényező, egyre nagyobb intenzitással befolyásolja a táj alakulását, működését. A kutatás célja a választott mintaterület antropogén-technogén táji mechanizmusának feltárása, a táj felépítésének és működésének megismerése. Mintaterületünk a Körös-Maros Nemzeti Park északi része Biharugra környékén. Fontos nemzetközi madárátvonuló és fészkelőhely, 1997 óta védettséget élvez. Határmenti elhelyezkedése a tájhasznosítás szempontjából speciális feladatok megvalósítását igényli a határ mindkét oldalán. Ezek közül fontos a környezeti tudatosság, a konfliktusok kezelése, az agrár- és vidékfejlesztés, valamint a környezet- és természetvédelem összehangolása. Fontos a település hatása is a tágabb környezet alakítására. A tájhasználat során elsősorban a terület természetvédelmi funkciójára kell figyelmet fordítani, ez pedig tudatos tájhasználatot jelent. A *legmegfelelőbb tájhasznosítás csak a környezetgazdálkodási és a fenntartható fejlődés alapelveinek a* figyelembevételével történhet. A tanulmány kísérletet tesz a biharugrai mintaterület jelenlegi tájökológiai állapotának meghatározására és a jövőbeni kezelés főbb szempontjainak megállapítására a természetvédelem és a tájtervezés számára. A kutatás eredményeinek gyakorlati alkalmazásával lehetőség kínálkozik a természetvédelmi határok bővítésére, szakmailag megalapozottá válhat az egységes európai zöldfolyosó-hálózatok kialakítása (ECONET, NATURA2000). A tényleges területhasználat és a területhasználat-korlátozási térkép összevetésével meghatározhatók azok a javasolt (ökológiai szemléletű) beavatkozások, amelyek elősegítik a Körös-Maros Nemzeti Park, a gazdálkodó szervezetek és a lakosság optimális területhasználatának kialakítását.

Summary: Nowadays, the main aim of landscape research is to find out how a land use type of a given area suits the land potential and what sort of social activities can take place there with the minimum risk. Humans, as determinant factors of the landscape, have more and more influence on the functioning and shape of the landscape. The goal of the research is to explore the antropogenic-technogenic processes along with the structure and function of the landscape. The study area is part of the Körös-Maros National Park and it can be found in the North of the park, near the village Biharugra. It is an important bird and wildlife habitat, protected since 1997. It is a peripheral rural landscape near the frontier, which means peculiar tasks for both sides of the border. The most important of these are raising the environmental awareness of the inhabitants, the handling of environmental conflicts, the harmonisation of agricultural and rural development with environment protection and nature conservation and to find out how the natural state of the settlements affect the wider environment. While using the land particular attention must be gave to nature protection, which means conscious land use. The most adequate land use can be chosen on the basis of the principles of environmental management and sustainable development. This study tries to specify the present landscape ecological state of the research area and to provide some guidelines for future nature conservation and landscape planning. By using the results of this research there is a possibility to extend nature conservation area and the unified European network of green corridors could be established (Natura 2000). Comparing the map of actual and limited land use we can determine all those suggested interventions wich will help to form the optimal land use for the inhabitants, the agricultural organizations and the National Park.

Keywords: landscape ecology, land use, biodiversity, geoecological mapping, ecotope – forming function, nature protection function

INTRODUCTION

The essay is introducing an interdisciplinary landscape ecology analysis in the Körös-Maros National Park, Kis-Sárrét area. The changes caused by human activities explain the neccessity of the research, as nowadays it is evident that people play an important part in shaping the land. The qualitative and quantitative characteristics of the relationship between nature and human are revalued.

Applied landscape ecology researches point out – from knowing a state of a land – how to work out an appropriate proposal for the future, which sketches the potential of the land around the examined area. Mainly the project is to fit the different social activities into the land with the least risk (*Miklós,* 1994).

The aim of the essay is to estimate the ecotope-forming functions and natural protection values of the land with the help of the connection between the protected and non-protected area's soil and vegetation in the Biharugra part of the Körös-Maros National Park. A further aim is to allocate all those potential land-shaping processes, which can determine the structure of the land use and the function of a given land.

The ecotope-forming function expresses the changing extent of the anthropogenic impact affecting the land. Because the natural protection value can be decreased very easily we have to give attention to preserve the species present. Knowing some land functions and comparing the actual land use with the map of limited land use, all those interventions can be specified which help to create an optimal land use of an area.

METHODS AND DATA

Our method of geoecological analysis lays the emphasis on the ecotopes as spatial cells of the ecosystem. During the examination of landscape function, estimating the biogenic factors is indispensable. The abiogenic factors have a great influence on the attributes of the biotopes and the ability of regeneration, evolution and the composition of the biogenic factors also depend on it (*Keveiné Bárány,* 2003). This complex view is better for practical use and it helps in carrying out real geoecological research and planning. (*Deák,* 2003.)

By the above-mentioned method, we classified the landscape patches (ecotopes) by taking the vegetation and plant association into consideration along with the dominant land use. The ecotope is determined in space, through the effects of biotic and abiotic components of the landscape.

Our task was to define the functions and the developmental tendency of the study area with the segregation of its homogenous units and examine their structure.

Considering the geoecological mapping the analysis consisted of three steps. Data collection meant separating the information into a database on the basis of remote sensing data of the maps and satellite imagery, monographies of the study area and some data of the descriptive mapping (examining the ground-water level, the vegetation, climate and the relief). Some geoecological data like the plant associations and soil samples of the vegetation patches were point-like data. By analysing the gathered soil samples we defined the type of soil with the help of customary soil examination methods. During our research work we accomplished a twenty-four hours-long microclimate measurement as well. The purpose of this measurement, carried out in a meadow called Nagy-Szik, was to acquire more microclimate data of the wide saline steppes. All these climate attributes and the special soil characteristics give an opportunity for specific vegetation to form.

While processing the data, we were using a special system called the Geographical Information System (GIS) just to establish the connection between the quantitative and qualitative attributes of these data. We used the following software: ArcInfo 7.0, ArcWiev 3.1, and ERDAS Imagine 8.2.

During the geoecological-based land evaluation we examined the filter- and buffer function of the sampled area, and we also had a look at the ecotope-forming and nature protection function too. The method of evaluating the ecotope-forming and nature protection values of different plant associations was published in 1997. *Keveiné Bárány (*1997) was the first to use this method. The following step of the synthesis was to visualise cartographically the evaluation of landscape efficiency (making a geoecology map). This process resulted in three maps made in a complex problem-orientated way.

Selection criteria for the investigated area and it's geographical characterisation

The study area called Kis-Sárrét belongs to the Körös-Maros National Park since the 8th of January 1997 (*Fig. 1*). This area (Kis-Sárrét) is located on a 0.7899 km^2 field near the frontier (borderline), south from the villages Körösnagyharsány, Biharugra, Zsadány, Mezőgyán, and Geszt. The area – isolated by both county border and frontier – is being considered a periphery from both economical-social and geographical view. It is very important to mention the almost untouched natural values, such as: wetlands, alkaline soils, plant communities, the species diversity caused by the mosaic land structure assign the land international significance. During the designation of nature conservation sites investigations aiming to achieve sustainable land use methods were not emphasised. The deficiency of this kind of examination is one of the main causes of the neccessity of geoecological research. To achieve this preservation of biodiversity it is inevitable to make sure that we keep an appropriate land-size and look after adequate- sized flora and fauna populations. We have to take into account all these principles during the protection (*Rakonczay,* 1998).

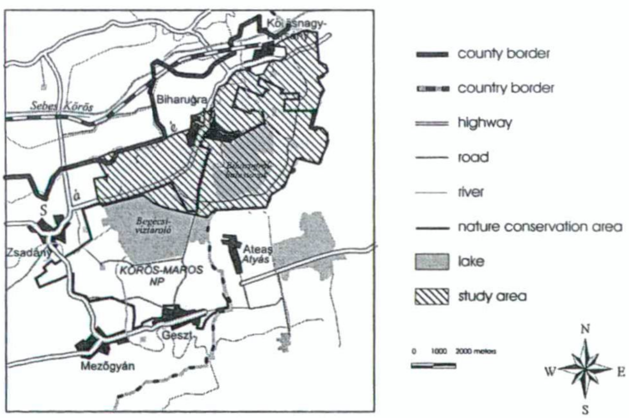

Fig. 1 Geographical location of the researched area

The research is examining the state of the biotic and abiotic factors, their interaction and operation around the sub-river basin. Our goal was to provide a basis, which can be useful in geoecological examinations for other areas.

Next we are going to survey some abiogenic factors which have influence on the geoecological system of the sample area.

Geographical characteristics of the study area

The Kis-Sárrét is a flat plain area on the alluvial fans south of Sebes-Körös with surfaces above 85-95 meters altitude. At present, Quaternary gravel, sand and clay predominate on the surface, which results in floodplain, meadow and alcalic soils. Around 1910 an embankment surrounded the swampy area of Biharugra. In the 1960s, the draining and filling up of nearby swampy areas established another part of the fishpond system. A canal connected to the river Sebes-Körös is the main water supply for the fishpond system (*Pécsi*, 1969).

In the 19th century the landscape has been changed by the regulation of the rivers and the building of agricultural drains. In 1905 there was a remarkable wave of artifical fishpond creation which significantly changed the landscape. The amelioration works in the 80ths and the above-mentioned anthropogenic actions resulted in a continuous drying up of the water meadows. The hydrography of the area is extremely varied. The Kis-Sárrét part of the Körös-Maros National Park is located on the 2500 km^2 river basin of the Sebes-Körös.

As a result of the frequent floods and diminishing arable lands in the year 1860 the Sebes-Körös was regulated and a new river bed was created. From this time on the former landscape of the flood basin consisted of a mosaic system of billabongs, dried-up rivers, dried-up surfaces, meadows and grasslands. In the hydrography respect the fishponds of the Begécs and Biharugra area belong to the central area of Kis-Sárrét. Those ponds were built in 1905. Nowadays it is 20.20 km^2 of which 16.57 km^2 are water surfaces and 2.62 km^2 are sedgy.

This area is quite rich in small canals and watercourses. In our study area – north-east from Biharugra – two patches of protected meadows can be found (Ugrai- and Sző-rét). They get their water supply only from precipitation but sometimes from the Biharugrai-Tápláló-drain in an artificial way.

Because of the good water supply conditions the whole area of Kis-Sárrét is extremely rich in groundwater. The difference of the groundwater levels between the humid and the arid periods reaches 3-4 meters at times. Therefore, the whole of this area is endangered by periodic groundwater flooding.

On account of the special geological structure the salt concentration in the groundwater is high and its wash-out is mostly weak. The waters of Pliocene layers contain high amount of sodium hydrogen carbonate and sodium chloride.

This area – in terms of the drying tendency of Alföld-Plain – is droughty and has arid mezo-scale climate. The micro-scale climate is quite important because it has a more extreme climate compared to its environment.

Its wildlife is adequate for the landscape potential. The ecosystem of our study area belongs to the Tiszántúl flora district; 40 protected and 3 strictly protected plant species can be found here. Concerning the fauna this is a part of the Közép-Duna fauna district and the Alsó-Tiszavidék.

Around Biharugra fishponds and wetlands have developed and temporarily they give an appropriate biotope for the migratory birds. The fishponds of Biharugra are perfect nesting, passage and resting places for all the nationally and internationally protected bird stock (e.g. white-goose). Several IUCN Red List bird species can be often seen around the place.

As we know, marsh reclamation, surface water drainage, deforestation, nitrification and the use of insecticides are the concomitants of water regulation and all of these processes cause drying out in wetlands which means the biotopes are exposed to danger. The plant associations of the wetlands, the reedbeds, marshlands and meadows are forced back to a small area. The ecosystem is degraded, and ruled by semi-natural conditions so many species have dissapeared. This area is a Ramsar site since 1996 and it also belongs to the Important Bird Areas (IBA).

RESULTS

Table 1 Landscape patches of the researched area

	Landscape patches
1.	reed-dominanted fens
2.	humid grasslands, meadows
3.	alkalic solonetz meadows
4.	water surfaces with duckweeds vegetation
5.	dry grasslands
6.	brook forest
7.	carolina poplar
8.	arable lands

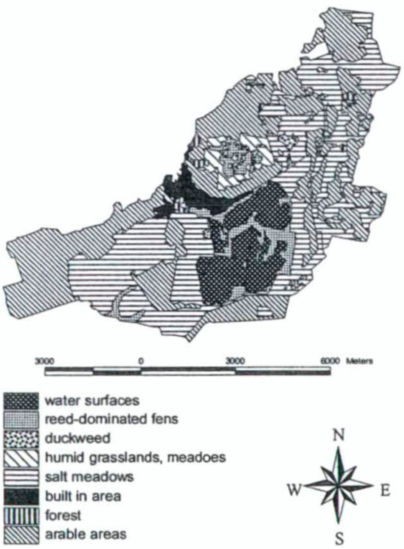

Fig. 2 Ecotopes of the study area

The structure of the landscape

One of the main points of geoecological research is to examine landscapes under the influence on human impact. On this sort of landscape mainly the crops are mixing with different kinds of weed plants. The arable lands and the fishponds are sometimes directly connected with the protected landscape patches, which results in conflict.

Surveying the area, all the available databases and the botanical and coenological survey of the protected areas (*Kertész,* 1997) helped us to choose the mosaically covered landscape patches (*Table 1*).

Determining the values of the ecotope-forming and nature protection functions and during the geoecological mapping procedure, we only examined those representative geoecological patches wich can also be mapped (*Fig. 2*).

We defined the ecotopes covering the land by the aggregation of the biotopes.

From the next examinations we left out the water surfaces of Ugrai-lake, the built in areas in Biharugra village and the forest patches. The attributes of the brookforest add to the attributes of the reed-dominated fens and humid grasslands patches. The dry grasslands' parameters add to the degraded vegetation of alkalic solonetz meadows and wet garsslands.

Buffer capacity of the soils

The soil is one of the most important abiogenic factors of the landscape processes. We accomplished the evaluation of the soil's filter capacity function with the earlier used analysis for geoecological mapping (*Leser and Klink,* 1988). To characterise the filter capacity we need the mechanical composition and the consistence of the soil.

The mechanical buffer capacity is the ability of the soil with which a part of the infiltrating contamination can be fixed. The soils usually have high mechanical buffer capacity, apart from the patches of brook forest and the humid grassland. Those two got medium value as a consequence of the permanently high level of ground water.

The physical-chemical buffer capacity namely the adsorption capacity primarily depends on the surface-associated activity. The patches of dry grasslands, fens and meadows have got high physical-chemical buffer capacity, the salt meadows and carolina poplars show medium values and finally the brook forest and humid grasslands have quite low buffer capacity.

Considering that the sample area is under protection we do not have to count on a serious polluting economical impact but some human activities make a contribution to metal accumulation in the soil. Unfortunately, the deposition of the communal waste of the surrounding local villages is not sorted out yet and the already existing waste piles are illegal. The heavy metals – with physical, chemical and biological transformation of the environment – can easily dangerously accumulate in some places. The buffer capacity of the soil concerning heavy metals is highly pH-dependant. Soil samples from the uppermost soil layer (30 cms) showed that the heavy metal fixing ability of the soils is strong in the brook forest and stronger in the other patches (*Mezősi and Rakonczai,* 1997).

Microclimatic characteristics of salt lands

The special microclimatic features of the salt lands and the soil characteristics make it possible for a unique vegetation to form. During a 24-hour microclimatic surveying we measured the air temperature, humidity, the wind speed and the temperature of the soils in 2-5-10-20-30 cms depths.

The measurements prove that the Nagy-Szik area has more extreme microclimate compared to its surrounding wetlands. The temperature fluctuation per day is relatively high; it even appears in the changes of soil temperature going down deeper, the amplitude shows decreasing tendency.

With the daily strong rise in the temperature, there was a powerful wind from the surrounding wetlands, of which the direction changed because of the decrease of the nightly temperature (*Duray and Hegedűs,* 2000).

Ecotope-forming values of the study area

The ecotope-forming function of the landscape patches was defined by the quantification of the maturity (M), naturalness (N), diversity (D) and the intensity of anthropogenic impact (A). The method we used is based on a German geoecological mapping technique and improved by the team of the Department of Physical Geography and Geoinformatics, University of Szeged (*Mezősi and Rakonczai,* 1997).

Maturity is the vegetation's successional stage. The long-lived complementary communities of the sampled area, which follow natural succession, are the following: alkalic solonetz meadows, meadows, dry grasslands and carolina poplar. All communities can be considered to be in a degraded phase, which is indicated by the anthropogenic effects. The humid grasslands, fens, brook forest and duckweed communities are more durable, stable and almost untouched.

Naturalness is indicating the regeneration ability of the community and all these are – even against the effects of disturbing factors – stable and the ecological potential of the habitat is suitable. The communities of the alkalic solonetz meadows, humid grasslands, fens, brook forest and duckweed represent higher levels of naturalness. The meadows, carolina poplar, dry grasslands have lower naturalness level.

The more diverse a community is, the more stable too. The measurement of diversity can be defined by the species richness (R) and the structural diversity (S). The reed-dominated fens, brook forest areas and dry grasslands are the richest in species. The communities of the meadows and humid grasslands show a medium value and the communities of duckweeds show low number of species. Compared to the surrounding places, the communities of carolina poplar, dry grasslands, alkalic solonetz meadows and duckweed have high structural diversity. We can conclude that the diversity (according to the richness of the species and the structural diversity) of the brook forest and dry grasslands areas is the highest. After this come the salt meadows and carolina poplar, the humid grasslands, meadows and finally the least stable so more sensitive reed-dominated fens and duckweed communities.

The most important anthropogenic affect the arable lands, the grazed dry grasslands and the carolina poplar influenced by forestry. There is little human impact on the meadows. The remaining areas show almost natural conditions in terms of conservation.

The ecotope-forming values change between 11 and 17 (*Table 2*). The communities of reed-dominated fens and brook forest have quite high ecotope-forming value (16.5-20) and it is also high in the duckweeds, alkalic solonetz meadows, humid grasslands and meadows (12.5-16). The ecotopes of dry grasslands and carolina popler are a bit lower (8.5-12).

Table 2 Ecotope-forming functions of mixed landscape patches

Type of plant communities	M	N	R	S	D	A	EV
reed-dominanted fens	4	5	4.5	1	2.25	5	16.25
duckweeds vegetation	4	5	1.5	1.5	1.5	5	15.5
humid grasslands, meadows	3.5	5	3.75	1	2.25	4.5	15.25
alkalic solonetz meadows	3	4	3.75	1.5	2.5	3.5	13

Dry grasslands are the richest in species which indicate degradation and the area's general richness of species is also considerable. The most stable, natural and diverse community is the brook forest. This ecotope can be found in the patches of reed-dominated fens and humid grasslands. Despite their low species diversity natural fens, humid grasslands and meadows are stable and have got high ecotope-forming value (*Fig. 3*).

The ecotope factor expresses the stability of the communities of the given area. If the ecotope-forming value is high, the stability and regeneration of the population is high as well. On the examined area the ecotope-forming value is above 11, it means that the present environmental impact does not reach a dangerous level.

Natural protection values of the study area

With the evaluation of the natural protection values (NPV) we can define the different protection demands for the different areas. One of the methods of defining the natural protection function is the above-mentioned German technique. In this case we need to define – apart from the ecotope-forming values (EV) – the rarity (R), endangered status (E), current values (C) and ability for regeneration (Re).

During the assession of natural protection we took into account the rarity of flora and fauna species and also their endangered status. The current value represents the percentage of the vegetation-pattern in the possible potencial vegetation. The ability of regeneration denotes the duration needed for the complete regeneration of the ecosystem.

The natural protection values change between 28 and 34. According to the results the brook forest fens and duckweed communities have quite high values (32.5-50) and require special protection. The remaining parts of the land, the humid grasslands, alkalic solonetz meadows, dry grasslands and carolina poplar have high natural protection values (24.5-32) and they are also natural conservation areas. In practice the natural protection function is altering in the areas of carolina poplar characterised by forestry and hunting activity. As a result of grazing on the patches of dry grasslands the vegetation is highly degraded. During the determination of natural protection values and its geoecological mapping we worked with aggregated landscape patches similary to the ecotope-forming values. In this way we got the natural protection values of the homogenous landscape units as it is seen in *Table 3*.

Table 3 Nature protection function of mixed landscape patches

Type of plant communities	EV	R	E	C	Re	NPV
reed-dominanted fens	16.25	2	5	5	4.5	32.75
duckweeds vegetation	15.5	2	5	5	5	32.5
humid grasslands, meadows	15.25	2	5	5	5	32.25
alkalic solonetz meadows	13	2	5	5	4	29

In the case of geoecological evaluation – apart from analysing the naturalness and human impact – we need to examine the ecological requirements of the species in detail. With describing the natural conservation aspects of the plant communities there is a possibility to allocate another kind of natural protection value. This technique takes the temperature-, water- and soil reaction of the plants into consideration (*Simon,* 1992; *Zólyomi et al.,* 1967). This kind of qualifying methodology was used to check our method.

Proposal for an optimal land use

Kis-Sárrét – appart from the strictly protected patches – is an area used by humans and it is the reason of how the current land use suits the attributes of the land. By the results of the data processing and evaluation and taking the present and future natural-social demands into consideration the proposal of an optimal land use in the near future could be accomplished. This prediction is based on geoecological maps, which are the products of geoecological mapping, made in different problem-orientated combinations.

Map of limited land use

The map of limited land use is a structural model edited by the results of geoecological mapping and the present land use (*Fig. 3*). According to the results of our investigation, on the strictly protected parts of the study area it is allowed to use the land as meadows and in some places as pasture (Ugrai-rét, Sző-rét, and Nagy-Szik); the carolina poplars are under forestry management. It would be advisable to discontinue all the agricultural work in this area.

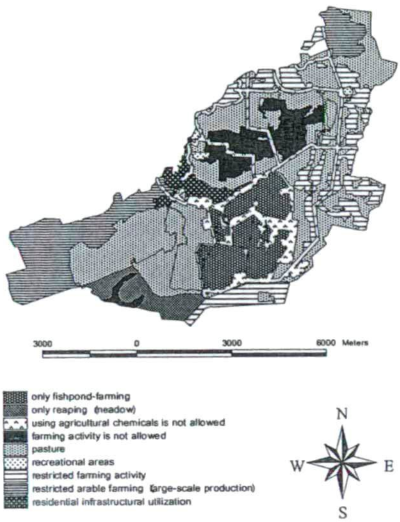

Fig. 3 Map of limited land use

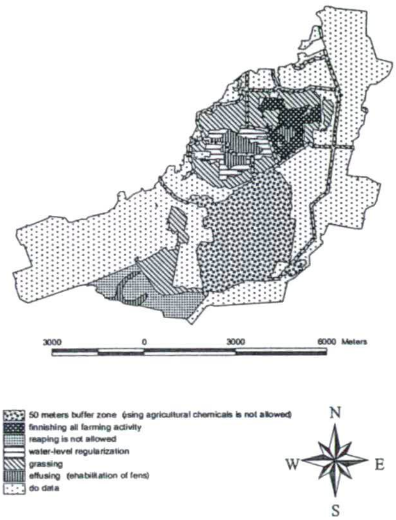

Fig. 4 Map of necessary ecological interventions

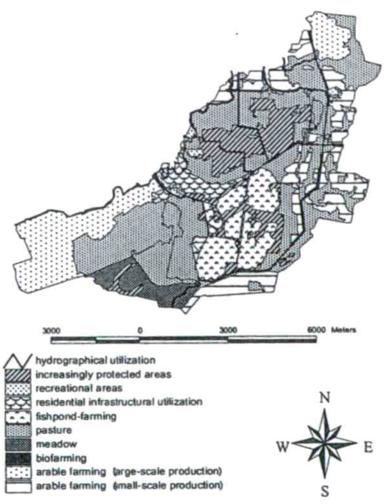

Fig. 5 Map of optimal land use

On the protected alkalic solonetz meadows the grazing and mowing are the most used forms of farming. When grazing, the animals can cause structural damage in the soil. Such processes take place on the dry grasslands (Cserepes-dűlő), therefore in this area only mowing should be allowed for the sake of the protection of the salt lands' plants. On the relict fens of Kis-Sárrét some fishponds have been formed (Biharugra fishponds).

The differently protected and mosaically structured ecotopes are in direct contact with the arable lands and this is the reason why some land use conflicts arise. In the small gardens near the border (Vaskapu-dűlő, Mályvás) only limited small-scale farming is allowed. West from Biharugra village the intensive large-scale farming is dominant.

The map of limited land use shows that about half of the study area (50.1%) belongs to a partly limited land use category. All these activities can be done without restriction but others are prohibited. On 40% of the land only controlled farming is allowed like fishing, grazing, mowing and recreational activities. On the strictly protected area it is justified to forbid every kind of farming. It means a 4.5% part of the land. On the parts lying around canals, rivers and fishponds (4.5) the natural environment should be protected by suppressing the agricultural chemicals (prohibited limitative category).

Map of necessary ecological interventions

The map of necessary ecological interventions is based on a dynamic model, which is edited on the basis of the map of limited land use and the demand for land use of the present and the future (*Fig. 4*).

On those areas which are strictly protected and proposed for amelioration the roads have to be given up apart from those for demonstration and treating.

For the sake of the protection of the soil and plants of the solonetz lands on Nagy-Szik it is inevitable to work out more strict rules on mowing and grazing cows.

On Cserepes-dűlő – for soil protection reasons – grazing has to be stopped. The rehabilitation of fen vegetation and the water-supply of the humid grassland are urgent tasks for the sake of the valuable bird species' biotope protection. In the near future a monitoring system has to be established, which should aim the prevention of the wetlands' further drying up. We also need to specify the origin and the amount of water subsitution.

For the protection of waters there has to be a buffer-zone designated fifty meters from the shoreline.

All the above-mentioned interventions correspond with the directives of the European Union and international agreements (Ramsar Sites, CITES etc.). Arable lands which are valueless, peripheral and have poor soil quality and low agricultural potential should be transformed into grassland.

Map of optimal land use

We achieved the map of optimal land use with the help of the prediction model of the geoecological mapping procedure. This map is deduced from the map of limited land use and the map of necessary ecological interventions (*Fig. 5*).

When using the land first we have to keep eyes on the function of the natural protection. It means a conscious land use and – where it is necessery –extending the border of natural protection. Extending the borders of natural protected areas towards Romania would fit the plans of European ECONET and NATURA 2000 system, which are uniform eco-corridor systems. It would connect the similar Romanian ecotopes to the protected Hungarian ones.

Because these landscape patches are mosaically structured homogenous units and directly connected to arable lands it is essential to designate buffer-zones to soften the degradation processes and human impacts.

Another conscious land use type harmonises traditional land use with the optimal land use and the nature protection ambitions. The untouched landscape, the closeness of the country border, the low income level and the unfavourable agricultural conditions are convincing reasons for qualitative soft-turism. Designating recreational areas and biofarming-zones are used to reach these goals.

CONCLUSION

By the geoecological mapping procedure there is an opportunity for multiaspect evaluation which takes into consideration the conditions, the potential and the risk factors of the areas. It is established that on the Kis-Sárrét part of the Körös-Maros National Park – a peripherial area having poor soil quality and low agricultural potential – the use of agricultural methods have to be decreased and more attention need to be paid to protect the salty land patches and wet biotopes. Applying the results of the methodology presented in this paper provides a very good possible way to shape substainable and euroconform land use for the land owners and users.

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MODELLING THE MAXIMUM DEVELOPMENT OF URBAN HEAT ISLAND WITH THE APPLICATION OF GIS BASED SURFACE PARAMETERS IN SZEGED (PART 2): STRATIFIED SAMPLING AND THE STATISTICAL MODEL

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Összefoglalás – Az urbanizált környezet lokális léptékű klímamódosulást eredményez a városok területén, amelynek legszembetűnőbb megnyilvánulása a magasabb hőmérséklet, az ún. városi hősziget. Kutatásunk célja az, hogy a városi felszínparaméterek, illetve matematikai-statisztikai módszerek segítségével az éves átlagos maximális hősziget intenzitására becslést készítsünk. A számításokban olyan új paramétereket is felhasználtunk, amelyek a város geometriáját három dimenzióban jellemzik. A felmérési módszer munkaigénye miatt a várost szerkezetében és térben reprezentáló, a teljes terület egyharmadára kiterjedő mintaterületen végeztük el vizsgálatunkat. Kiválasztását az ún. rétegzett mintavételezési eljárással készítettük. A statisztikai vizsgálataink azt bizonyítják, hogy a kompaktsági mutató a széles körben elfogadott égboltláthatóság paraméternél is erősebb kapcsolatot mutat a hősziget intenzitással. Lépésenkénti lineáris regressziós eljárás segítségével alkottuk meg azt a modellt, amellyel – felhasználva a területről származó különféle felszínparamétereket – már becslést készíthetünk a városi hősziget területi szerkezetére. Az eredmények azt mutatják, hogy a modellezett hőszigeti mező képe csak kis mértékben tér el a valóságos állapottól, ami bizonyítja az új paraméterek jelentőségét, és a mintaterület kiválasztásának helyességét.

Summary – Our investigations concentrated on the urban heat island (*UHI*) in its strongest development during the diurnal cycle in Szeged, Hungary. In order to quantify the effect of the peculiar urban structure on the development of the mean annual urban heat island we determined a new surface parameter (weighted volumetric compactness) which characterises the volume, the building plan area and the thermodynamic role of the buildings at the same time. The calculation of this new parameter required a large-sized digital database that includes more than 22,000 building's 3 dimensional measurement. Because this would take a long time, we concentrate the investigation on a smaller but representative sample area, as the first step of our research. Our task included the development of statistical models using urban surface parameters (built-up and water surface ratios, sky view factor, building height, weighted volumetric compactness). Model equations were determined by means of stepwise multiple linear regression analysis. As the results show, there is a clear connection between the spatial distribution of the *UHI* and the examined parameters (built-up and water surface ratios and weighted volumetric compactness), so these parameters play an important role in the evolution of the *UHI* intensity field. The distribution of the difference between the modelled and the (independent) annual mean maximum heat island intensity show that we could calculate the heat island's spatial distribution properly from the sample area's dataset.

Key words: Urban heat island, urban surface parameters, weighted volumetric compactness, representative sample area, stratified sampling, stepwise multiple linear regression model, Szeged, Hungary

1. INTRODUCTION

The first part of this paper (*Balázs et al.*, 2005) and the earlier studies have described the investigation area, and the method of measuring the temperature and surface parameters

(*Sümeghy and Unger*, 2003; *Unger*, 2004). In order to quantify the effect of the peculiar urban structure on the development of the mean urban heat island a new surface parameter (weighted volumetric compactness) was determined which characterises the volume, structure and thermodynamic role of buildings at the same time. In this paper, we use this dataset, but disregard the detailed description of the measuring methods. In order to study microclimate alterations within the city, the utilization of statistical modelling may provide useful quantitative information about the spatial and temporal features of the urban temperature excess by employing different surface parameters (*Oke*, 1981).

Our purpose is to investigate the quantitative effects of the relevant surface parameters on the *UHI* patterns. These factors are: the built-up ratio, the water surface ratio and the sky view factor. Our task is to prove that the connection between the compactness and the annual *UHI* intensity is significant, and we would also demonstrate that this new parameter is a useful part of our statistical model.

2. STUDY AREA AND METHODS

2.1. Selection of the sample area

As we already mentioned, in our project we plan the measuring of the characteristic geometrical and morphological parameters in the whole area. It is important because we would like to determine the connection between these parameters and the *UHI* intensity. Such a detailed and large-scale analysis of urban geometry – as far as we know – is without precedent in the region.

In the investigated area the number of the houses is more than 22,000. Presumably, it would have taken too much time to measure the parameters of this enormous number of buildings. Therefore, we decided on conducting our research in a smaller area. To prove that these parameters have a significant role in developing of the *UHI*, we did our research in a representative sample area including 35 cells from the 107-cell grid network. This makes statistical investigation possible and less time is needed for the measurements.

2.1.1. Stratified sampling

Stratified sampling is a sampling design in which prior information about the population is used to determine groups (called strata) that are sampled independently. Each possible sampling unit or population member belongs to exactly one stratum. There can be no sampling units that do not belong to any of the strata and sampling units that belong to more than one stratum. When the strata are constructed to be relatively homogeneous with respect to the variable being estimated, a stratified sampling design can produce estimates of overall population parameters (e. g. mean, proportion) with greater precision than estimates obtained from simple random sampling.

If the investigator has prior knowledge of the spatial distribution of the study area, the strata should be defined so that the area within each stratum is as homogeneous as possible. The variable providing the information used to establish the strata (the so-called „auxiliary variable") was the built-up ratio.

The fact, that the increase in precision depends on the strength of the correlation between the auxiliary variable and the outcome variable to be estimated, may theoretically be a restricting factor. If there is not any significant correlation between the auxiliary variable and the one being estimated, the precision of the final estimation can be significantly decreased.

The strata should be determined before allocating the sample sizes. When the strata are defined according to an auxiliary variable that is correlated with the variable to be estimated, the optimal definition of the strata is that the population included in each stratum should be as homogeneous as possible with respect to the auxiliary variable.

Cochran (1963) offers some guidelines on how to optimally assign strata when the auxiliary variable is continuous. If there is a particular interest of estimating the overall mean for the population, Cochran suggests defining no more than six strata and using a procedure attributed to *Dalenius and Hodges* (1959) to determine the optimal cutoff values for each of the strata based on the distribution of the auxiliary variable for the population. In this study six layers have been defined and the samples have been arranged into layers by applying the method of *Dalenius and Hodges* (1959).

Table 1 shows the final result of defining the six layers.

Table 1 Number of cells in each layer, and the number of cells by layers

Strata	Cutoff values (built up ratio in %)	In layers	In samples
#1	$B \leq 25.84$	11	4
#2	$25.84 < B \leq 43.56$	14	5
#3	$43.56 < B \leq 58.80$	18	6
#4	$58.80 < B \leq 71.68$	20	7
#5	$71.68 < B \leq 83.60$	22	7
#6	$83.60 < B$	18	6
Total		*103*	*35*

2.1.2. Selection by the spatial distribution

With the stratified sampling we allocated the number of the samples from each strata. After that the random selection of the cells could be an adequate solution, but if we have considered other aspects the outcome would be better. We had two considerations. First of all we decided that the cells should be distributed evenly. Furthermore, we had to choose the cells where the horizontal thermal gradient was high when the *UHI* developed.

From the possible variations we have chosen the one whereof we could interpolate the spatial distribution of the *UHI* with the minimum deviation. As a result of this process, cells of the chosen sample area are relatively well scattered all over the research area (*Fig. 1*). In those places where the chosen cells are located near each other, the horizontal temperature gradient is high in the time of the development of the *UHI*.

2.2. Construction of the stepwise multiple linear regression model

In order to assess the extent of the relationships between the annual mean maximum *UHI* intensity (ΔT) and various urban surface factors, multiple linear regression analyses were applied. To determine model equations we used ΔT as predictant (dependent variable) and the afore mentioned parameters as predictors: ratios of built-up surface (B) water surface (W), mean sky view factor (SVF), average compactness (C_m) and weighted volumetric compactness (C_v) by cells.

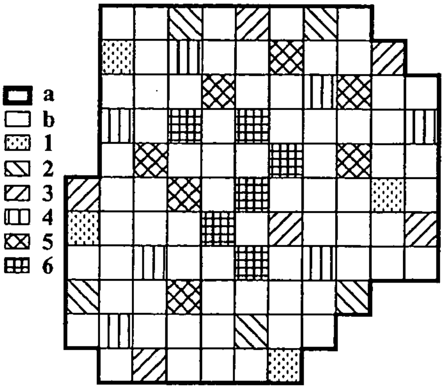

Fig. 1 Distribution of the cells of the sample area in the investigated area: (a) border of the investigated area, (b) cells not included in the sample area, (1-6) cells selected from the given layers

According to the results of previous studies the connection between the urban surface parameters (*B*, *W*, *SVF* and *H* = building height) and the mean *UHI* intensity is well-describable by a linear function (*Bottyán and Unger,* 2003; *Bottyán et al.,* 2003). Thus, constructing the present model, we also applied the linear-based approach.

We presumed that all five parameters have significant impact on the spatial distribution of the *UHI*. First, all factors were included in the database (as predictors). We selected the statistically acceptable predictors, later applied in the model, by the stepwise linear regression method. In the process we applied the SPSS for Windows 9 software. Limits of predictors were entered or removed from the model depending on the significance of the F value of 0.01 and 0.05, respectively.

3. RESULTS AND DISCUSSION

3.1. The representativity of the sample area

Because of the stratified sampling being based on the built-up ratio, we examine the sampling method's errors with this parameter. Because of the sampling method we only have to examine how representative the sampling is for the spatial distribution of the whole dataset.

It would not be appropriate to study the spatial representativity of the selection by using the spatial distribution of the interpolated values of the built-up ratio, since none of the interpolation methods are suitable for the spatial extension of such a rhapsodically changing parameter. Earlier studies proved the significant connection between the built-up ratio and the *UHI* intensity (e.g. *Unger et al.,* 2000). Therefore we examine the representativity by the application of the *UHI* field. We interpolated the spatial distribution of the *UHI* intensity based on the complete database, and also based on the data of the selected 35 cells. The later version of the heat island field is more simplified and the run of isotherms is more settled, less detailed, but in its main characteristics it is basically similar to the *UHI* field based on the complete database (*Fig. 2a-b*).

Neglecting the smaller structural characteristics, only small-scale differences occur, and in case of three-fourth of the area this difference does not even reach 0.1°C (*Fig. 3*). The mean of the differences is -0.035°C, the standard deviation is 0.11°C. In order to identify the value significantly different from the mean deviation, the limits of confidence interval belonging to the database had to be calculated (at 5% significance level). Thus, we can find those areas where the error is especially great, namely the cases where the selection was not appropriate. Significant positive differences occupy 0.1% of the area, negative differences occupy 3% of the area.

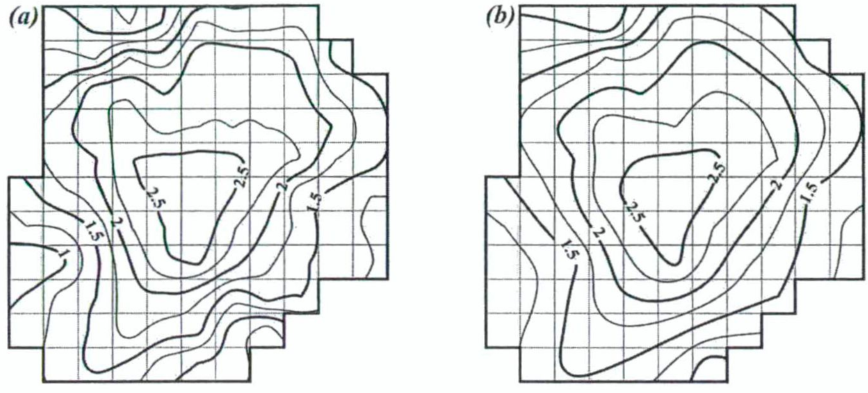

Fig. 2 Spatial distribution of the annual mean maximum urban heat island intensity (a) based on the complete database and (b) based on the data of the selected 35 cells (April 2002 – March 2003)

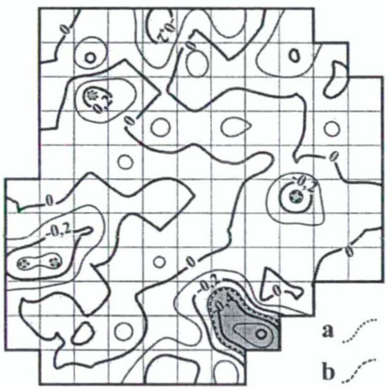

Fig. 3 The distribution of the difference between the annual mean maximum urban heat island intensity based on the complete database and based on the data of the selected 35 cells (April 2002 – March 2003), a - the upper limit of the confidence interval (0.25°C), (b) the lower limit of the confidence interval (-0.32°C)

The small values of deviation prove that the two structures are mainly similar and therefore the selection process was successful. Nevertheless, it is still important to take into account the afore-mentioned deviations because they present the maximum accuracy of the heat island field based on the later-discussed model equation.

3.2. The relationships between the surface parameters and the UHI

Firstly we started to assess the relationships between the mean maximum *UHI* and the surface parameters, we analysed the connection pairs-wise using the data from 35 cells. During this process we identified the formulae (according to the $y = ax + b$ general form) of linear regression lines referring to the closeness of the stochastic connection between each parameter and the ΔT as well as the values of the determination coefficient (r^2) and the values of standard deviation around the regression line (σ_R).

The null-hypothesis, namely that there is no real connection between two chosen parameters, can arise only in those cases where the value of the determination coefficient is large enough. The acceptancy interval of the null-hypothesis, in case of 35 elements on 5% significance level was $r^2 > 0.1089$ (*Péczely,* 1979).

Table 2 The statistical relationships between the *UHI* intensity and the surface parameters

Parameter	Linear regression equation	r^2	σ_R
B	$\Delta T = 0.0165 \cdot B + 0.8005$	0.6619	0.293°C
W	$\Delta T = -0.0019 \cdot W + 1.7965$	0.0011	0.5041°C
SVF	$\Delta T = -3.4219 \cdot SVF + 4.8782$	0.3584	0.404°C
C_m	$\Delta T = 0.363 \cdot C_m + 0.9351$	0.2976	0.423°C
C_v	$\Delta T = 2 \cdot 10^{-7} \cdot C_v + 1.4827$	0.5243	0.348°C

Based on the statistical parameters (r^2, σ_R) we can pronounce that the closest connection is between the values of the B and the ΔT. The trend is positive, so when the value of the built-up ratio is increasing the *UHI* intensity is increasing too. (*Table 2*) This is not a surprising result as the main reason of choosing this sample area was exactly the above-mentioned parameter.

The trend is negative between the *SVF and* ΔT, so when the value of the sky view factor is increasing the *UHI* intensity is decreasing. The connection between the *SVF* and the ΔT is statistically significant (*Table 2*), although the value of the r^2 was a bit under our expectations based on previous research (*e.g. Oke* 1981; *Unger* 2004).

There is not close connection between the C_m and the ΔT, however there is real connection based on the determination coefficient. The trend is positive so if the value of C_m is increasing the ΔT will increase at the same time (*Table 2*).

Our hypothesis, namely that C_v parameter is an essential factor in the heat-island development and therefore there is strong stochastic connection between them, was proved by the previously-done correlation examination (*Table 2*). Based on the regression equation, it can be stated that with the increase of the C_v values the temperature difference undoubtedly grows, too (*Fig. 4*). The recently introduced determination coefficient belonging to the C_v parameter is close to the value of the built-up ratio. On the basis of these preliminary results we can conclude that in the explanation of the mean maximum *UHI* intensity structure the C_v parameter carries significantly more information than the widely-accepted surface-parameter, the *SVF*.

3.3. The results of stepwise multiple linear regression

By the application of the above-mentioned method, out of the five original predictors three were statistically acceptable for the estimation of the *UHI* intensity (*Table 3*). The importance of these three parameters in the development of temperature excess was almost 80% ($r^2 = 0.786$). The model is acceptable even on a significance level less than 0.1%, and thus the estimation based on this model is highly reliable. This fact clearly shows that by entering the afore-mentioned parameters, the increase of the value of the explained determination coefficient (r^2) decreases stepwise. The entering of the C_v parameter resulted in a 9.2% increase in the explained correlation, then predictor W adds to this value a further

3.2%. The application of the fourth and fifth parameters (*SVF*, C_m) does not provide more information to the model in practice, and thus, they can be discluded from the model. In case of the *SVF* this fact is quite surpising, because – according to some earlier studies (*Bottyán and Unger,* 2003; *Unger et al.,* 2004) – strong correlation was detected between the *SVF* and the ΔT. This can be explained by the probable fact that it is in multi-collinearity with the C_v, as both parameters are referring to the vertical structure of the town, and therefore only the stronger predictor appears in the model. The fact that the C_v, is a strong predictor in the model confirms our previous theory based on physical experience.

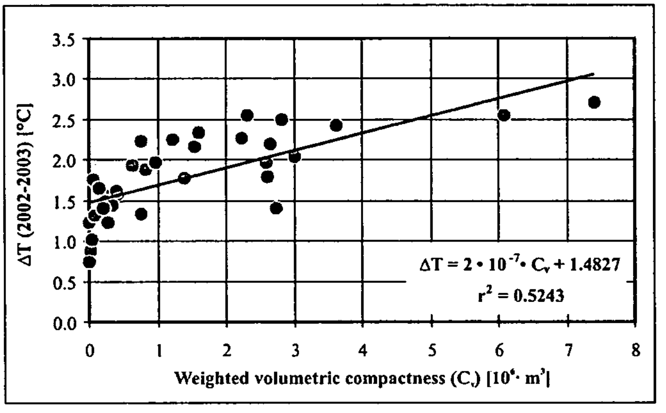

Fig. 4 Relationship between the annual mean *UHI* intensity (ΔT) and weighted volumetric compactness (C_v) (n = 35)

Table 3 Values of the stepwise correlation of mean maximum *UHI* intensity and urban surface parameters, as well as their significance levels in Szeged (n = 35)

Parameter entered	Multiple $\|r\|$	Multiple r^2	Δr^2	Significance level
B	0.814	0.662	0.000	< 0.001
B, C_v	0.869	0.754	0.092	< 0.001
B, C_v, *W*	0.886	0.786	0.031	< 0.001

Table 4 Values of coefficients, standard errors and significance levels of the applied urban surface parameters of the models in Szeged (n = 35)

Parameter	Coefficients	Standard deviations	Significance level
B	$1.332 \cdot 10^{-2}$	0.002	< 0.001
C_v	$1.045 \cdot 10^{-7}$	0.000	0.002
W	$1.082 \cdot 10^{-2}$	0.005	0.041
Constant	0.809	0.123	< 0.001

Afterwards, on the basis of the sample data, an estimation is given for the value of the regression model coefficients (*Table 4*). This is important because in case of known coefficients the model-equation can be described. By this equation it is possible to estimate the heat island intensity of the cells and thus spatial structures can be constructed. It appears in the *Table 4* that the estimation of coefficients is especially good, as significancy values are above 95% in all case. What is more, this value is smaller than 99% only in case of W parameter. The model-equation is calculated as follows:

$$\Delta T = 1.332 \cdot 10^{-2} \cdot B + 1.045 \cdot 10^{-7} \cdot C_v + 1.082 \cdot 10^{-2} \cdot W + 0.809$$

With the application of the equation, it is possible to provide the estimated value of any of the 35 cells. In this statistical model, special attention must be paid to the problem of extensibility, namely that the model can be applied only to parameters with values between the minimum and maximum values applied in its creation. In this case, however, the above-mentioned fact does not have any determining effects. Nevertheless, when applying the model to another town, it has to be considered whether the used predictors are within the adequate intervals. As the limits of extensibility, intervals are given in *Table 5*.

Table 5 The maximal and minimal values of predictors in the model

Parameter	**minimal values**	**maximal values**
B (%)	3.24	93.8
C_v (m^3)	1849.54	7411700.05
W (%)	0	40.36

With the help of the Kriging interpolation method (linear variogram-model application), the already-calculated ΔT values provided a basis to the spatial extension of the above-mentioned values. Using this extension, it is possible to define the spatial structure of the *UHI* intensity and thus the whole mean heat island can be detected, practically without any temperature measurements (*Fig. 5a*). Naturally, it is useful to test the model and thus, to compare the ΔT field calculated by the model-equation to an independent database collected in another time period.

3.4. The results of spatial extension and model-verification

We studied the accuracy of the heat island field estimated by the model-equation (*Fig. 5a*) in a number of steps. The independent temperature measurements, which took place between March 1999 and February 2000, were taken as reference data referring to the calculated heat island intensity values of the town.

The first step was to calculate the difference between intensity values of the heat island estimated by the model-equation and real intensity data interpolated from the values of the sample area (*Fig. 5b*). On the basis of these differences we can conclude that the model overestimates real values: the mean deviation is 0.22°C. The absolute deviation, which is smaller than 0.1°C, extends to more than one-third of the whole study area.

With the help of the determined bounds of the confidence interval belonging to the data set we can recognise the areas with especially striking errors. In these areas the estimation of the model significantly differs from the value of mean error. In the estimation of the model, greater negative errors appeared at less than 1% of the study area, while in case of positive ones, this area-ratio was around 3%.

The difference map (*Fig. 5b*) shows those places where the result of modelling was not entirely acceptable. These deviations can be explained by the fact that the model does not take into account values of neighbouring cells that is the equalising effect, which indirectly appears in the given cell while creating the measured *UHI* intensity. In the area of greater positive deviations the problem is that the estimation gives the same values to the cells of suburbs than to the densely built-up downtown cells. There is only one cell with negative deviation: this is presumably caused by the effect of the river Tisza and thus the values of surface parameters decrease. Since temperature is not able to follow this sudden change real temperature must be higher than the estimated one.

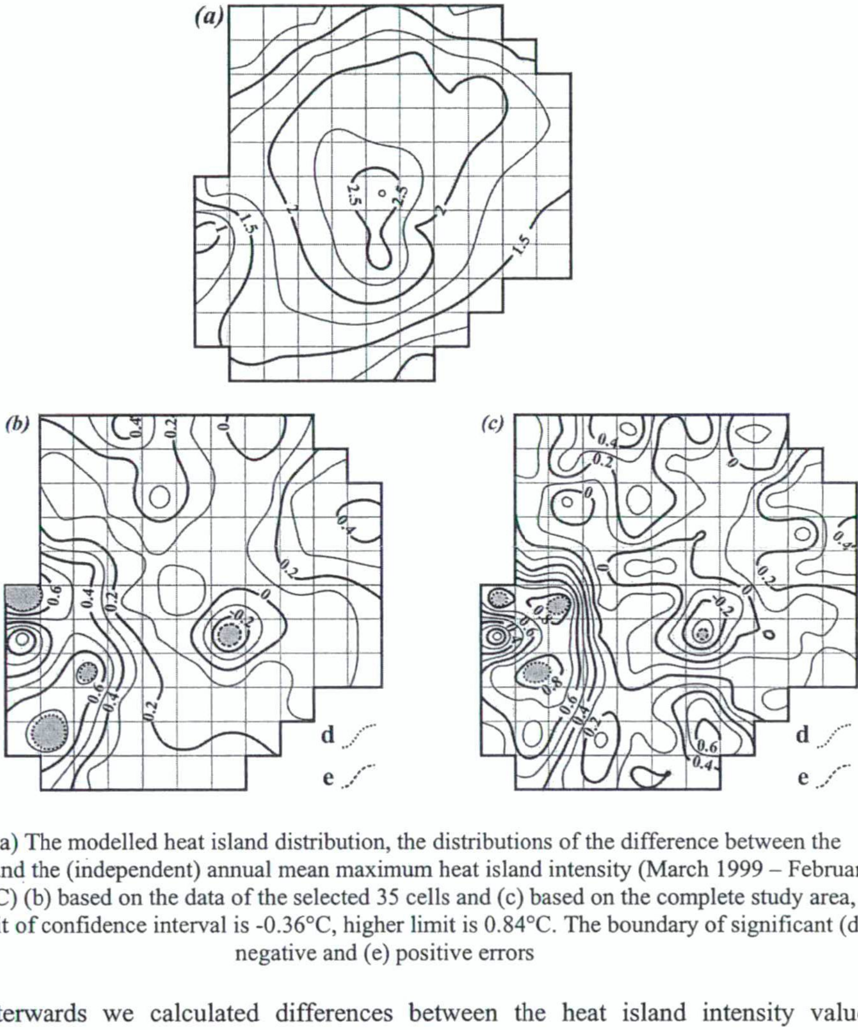

Fig. 5 (a) The modelled heat island distribution, the distributions of the difference between the modelled and the (independent) annual mean maximum heat island intensity (March 1999 – February 2000) (°C) (b) based on the data of the selected 35 cells and (c) based on the complete study area, lower limit of confidence interval is -0.36°C, higher limit is 0.84°C. The boundary of significant (d) negative and (e) positive errors

Afterwards we calculated differences between the heat island intensity values estimated by the model-equation and the real heat island intensity values of the entire study area of 103 cells (*Fig. 5c*). On the basis of these differences, the mean error of the model and the extension was 0.24°C, which is not much more than the error of the model in itself. The statistically large-sized error extended only to a part of the area, smaller than in case of the above-mentioned difference. Errors appearing in the previous case are the results of the selection, although they are much less notable in size.

Taking all these factors into account, we can state that values estimated by the model are closely related to the independent values of the above-mentioned series. In the analysis of deviations, we have to consider the fact that on the basis of data taken from the sample area a pattern of the whole heat island can be provided with few errors. The spatial structure of larger differences points to the fact that by possessing the database of the whole area a more adequate model can be created if we also include the characteristics of the neighbourhood around the given cell.

4. CONCLUSIONS

Our aim was to create a model in order to estimate the intensity and spatial distribution of the mean maximum heat island, with the help of urban-surface parameters as well as mathematical-statistical methods. In the course of this work we applied some new parameters which describe urban geometry in three dimensions. Out of these two parameters, the application of spatial compactness as a predictor appeared to be more successful in the model.

As far as we know, such a detailed measurement and analysis of surface geometry for urban climate research have not yet been carried out in our region. Because of the size of the town, as a first step we studied only one sample area representing the whole structure of the town, but not the entire town. The selection of the sample area was carried out by the method of stratified sampling, of which the basic index-number is the built-up ratio, the most important urban surface parameter. After the establishment of the six layers we chose one-third of each class, paying special attention to the spatial distribution. Moreover, it was an important task to represent those areas where large horizontal temperature gradient can be detected in time of development of the *UHI* maximum.

In the course of our research it was possible to measure the spatial data of 11,000 buildings with great accuracy and thus, we could perform a more complex analysis of the connection between urban geometry and the heat island. The compactness, similarly to the predictors describing the urban surface, strongly correlates with the *UHI* intensity; in addition, it became clear that it provided an even stronger connection than the internationally-accepted *SVF* parameter.

With the application of the stepwise multiple linear regression model we could determine coefficients showing in what extent each parameter takes part in the creation of the annual mean *UHI* intensity. Using this model-equation, the absolute deviations – calculated for an independent one-year period – of the spatial extension of the generated heat island remained under 0.5°C almost in the entire investigated area of the town, which is an appropriate result. The structure of the calculated heat island in its characteristic features also showed clear similarities to the real conditions.

In this study, one part of the current results in the urban climatology research of Szeged is discussed in detail. The next step of our project is to finish the 3D urban geometry survey, which helps us to provide a more exact model of the *UHI*. Moreover, in this model it becomes also possible to take the neighbouring cells into consideration. Our further aim is to extend the model towards other towns with favourable conditions for urban climate research (e.g. Debrecen, Hungary). Thus it would become possible to build up such a general model that would enable us to calculate the spatial extent of the mean maximum heat island, practically without any temperature measurements, merely with the application of urban surface parameters. Such data are available for more and more settlements. Therefore, by estimating heat island structure and intensity, which have significant influence on energy consumption and comfort sensation, such a simple model can provide an adequate help in urban planning.

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DIFFERENCES IN HUMAN COMFORT CONDITIONS WITHIN A COMPLEX URBAN ENVIRONMENT: A CASE STUDY

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Összefoglalás – Az utóbbi években számos indexet (például a PMV – Predicted Mean Vote és a PET – Physiological Equivalent Temperature) fejlesztettek ki annak számszerűsítésére, hogy mekkora az emberi szervezetet érő hőterhelés különböző környezetben, illetve milyenek az emberi test és a környezete közötti energiaáramlási viszonyok. A természetes felszínekhez képest az összetett városi felszín olyan speciális mikroklimatikus sajátosságokkal jellemezhető környezeteket teremt, amelyek jelentősen befolyásolják az emberi test energiaegyenlegét. Jelen vizsgálatunkban egy esettanulmányt mutatunk be a 160.000 lakosú Szeged példáján. A sugárzási áramlások erőssége számos tényezőtől, így a felszín szerkezetétől és a beépítettség sűrűségétől függ. Mintaterületünk a város magas beépítettségű belvárosi régiójában található, szűk utcakanyonok jellemzik, 20-30 éves (20-30 m magas) útszéli fasorral. A sugárzási viszonyok tehát ezen feltételeknek megfelelően módosulnak. Az összetett városi környezetek mikroklímája humán-bioklimatikus hatásának megbecslése a PET index segítségével történt. Az indexszámításokat a RayMan modell segítségével végeztük, melynek során egymáshoz közel fekvő, de az épületek és a fák által eltérően árnyékolt helyek bioklimatológiai körülményei kerültek összehasonlításra. Az eredmények szerint a besugárzási különbségek következtében akár 15-20°C-os eltérések is adódhatnak a PET értékekben.

Summary – Several complex thermal indices (e.g. Predicted Mean Vote and Physiological Equivalent Temperature) have been developed in the last decades to describe and quantify the thermal environment of humans and the energy fluxes between body and environment. Compared to open spaces/landscapes the complex surface structure of urban areas creates an environment with special microclimatic characteristics, which have a dominant effect on the energy balance of the human body. In this study, outdoor thermal comfort conditions are examined through a field survey in Szeged, a South-Hungarian city (population 160,000). The intensity of radiation fluxes depends on several factors, such as surface structure and housing density. Since our sample area is located in a heavily built-up city centre, radiation fluxes are mainly influenced by narrow streets and several 20-30 year old (20-30 m tall) trees. Special emphasis is given to the human-biometeorological assessment of the microclimate of complex urban environments through the application of the thermal index PET. The analysis is carried out by the utilization of the RayMan model. Bioclimatic conditions of sites located close to each other but shaded differently by buildings and plants are compared. According to the results differences in the PET index amongst these places can be as high as due to the different irradiation.

Key words: urban environments, thermal comfort, Physiological Equivalent Temperature PET, Szeged, Hungary

1. INTRODUCTION

Human beings are subjected to various kinds of stress in the urban environment. The most important ones are the meso- and microclimatic conditions, which differ significantly from that of rural areas. The main reason for this is the alteration of the surface structure (e.g. proportion of the built-up area, 3D geometry of the buildings and trees) triggering particular urban climate phenomena (e.g. urban heat island, changes in the radiation fluxes).

An important task of bioclimatological research is to evaluate the thermal environment of human beings, since it determines the energy balance of the body and consequently its comfort sensation (*Höppe,* 1993). The physiologically relevant assessment of urban climate, and especially different urban microclimates, requires the use of methods and indices which combine meteorological parameters with thermo-physiological parameters (*Mayer*, 1993; *VDI*, 1998). Urban and regional planners are demanding easily understandable methods for the measurement of the thermal component of climate in order to facilitate the development of comfortable urban microclimates (*Höppe,* 1993).

Human bioclimatological studies carried out in summer have a specific importance, because the urban heat island forming several hours after the sunset keeps the extent of the heat stress at high levels in addition to the strong heat stress during daytime. This shortens the regeneration possibilities of urban residents during the night. Based on the foregoing, we can state that the human thermal comfort issues and quantitative bioclimatological indices generate valuable information for urban planners and architects. The obtained data and suggestions can contribute to the planning process to achieve more a more suitable and healthy urban environment, e.g. to increase the well-being of the urban population by mitigating heat stress in summer.

This study is based on earlier bioclimatic and recent urban climate studies in the South-Hungarian city Szeged. According to these studies an urban heat island intensity of 2.7°C on annual average can be measured in Szeged, which can increase to 6.8°C during clear, anticyclonal weather conditions (*Sümeghy and Unger*, 2003). The results show a significant additional heat load to the human body, especially in summer. In former bioclimatic studies, with the aid of suitable indices for the available data set, differences in the annual and diurnal variation of human bioclimatic characteristics between an urban and rural environment were evaluated over a 3-year period (*Unger*, 1999). These indices were the thermohygrometric index (THI), defined by air temperature and relative humidity, the relative strain index (RSI), defined by air temperature and vapour pressure, and additionally the number of "beergarden days" defined by air temperature at 21.00 hours. It was shown that, due to the increased heat stress, the modification effect of the city is rather negative in summer, while it improves the thermal sensation by shortening the unfavourable cold periods in winter.

The aim of this study is to demonstrate the importance and potentials of the quantitative evaluation of human comfort and heat stress. Findings are of use for city planning and architects, as shown for in the case of the city of Szeged, situated in the southern part of Hungary. The evaluation based on sophisticated microclimate measurements in different urban micro-environments within the study area to reveal their human bioclimatological features.

2. MATERIAL AND METHODS

2.1. Study area

Szeged is located in the southern part of Hungary (46°N, 20°E) at 79 m above sea level on a flat plain (*Fig. 1A-B*). River Tisza passes through the city; otherwise there are no large water bodies nearby. The base of the street network is a circuit-avenue system, with several different land-use types from the densely built centre to the detached housing suburb region (*Fig. 1C*). The city's population of 160,000 lives within an administration district of 281 km^2, but the highly urbanized area is restricted to an area of about 30-35 km^2.

Szeged belongs to the climatic region *Cf* according to Köppen's classification (temperate warm climate with uniform annual distribution of precipitation) or in the climatic region *D.1* according to Trewartha's classification (continental climate with a long warm season) (*Péczely*, 1979). The annual mean temperature is 10.4°C and the amount of precipitation is 497 mm.

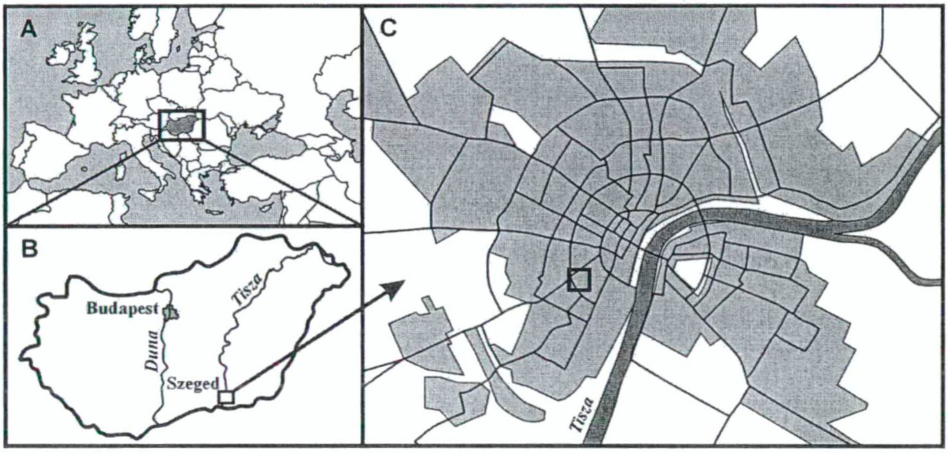


Fig. 1 Geographical location of Hungary in Europe (A), of Szeged in Hungary (B), built-up area and road network of the city (C) and the location of the 200 x 200 m sample area in the city

The investigated sample area (200 x 200 m) in Szeged is situated in the heavily built-up city centre region with narrow streets and several 20-30 years old (20-30 m tall) deciduous trees (*Fig. 2*). The area is crossed by a busy road (Petőfi av.) with a tram rail in a direction of NE-SW and by two narrow by-streets. One of the by-streets (Batthyány str.) has a NNW-SSW direction and the other (Egyetem str.) is parallel to the avenue. The area is dominated by the five-storey building complex of the University of Szeged.

2.2. Applied bioclimatic indices

In the last decades, several models have been developed to estimate the energy balance of the human body in different environments. These models usually include various meteorological parameters, albedo of the surface and solid angle proportion (*Fanger*, 1972; *Gagge et al.*, 1986; *Höppe*, 1999; *Matzarakis et al.*, 2000; *Spagnolo and de Dear*, 2003). The models utilize complex comfort indices – for example Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET) or OUT SET* – to evaluate the thermal stress affecting the body. Most of the indices include the mean radiant temperature (T_{mrt}), which is, especially during sunny weather, the most important input parameter for the energy balance (*Matzarakis et al.*, 2000). T_{mrt} is defined as the uniform temperature of a surrounding surface giving off blackbody radiation (emission coefficient $\varepsilon = 1$) which results in the same energy gain of a human body as the prevailing radiation fluxes (*Matzarakis et al.*, 1999).

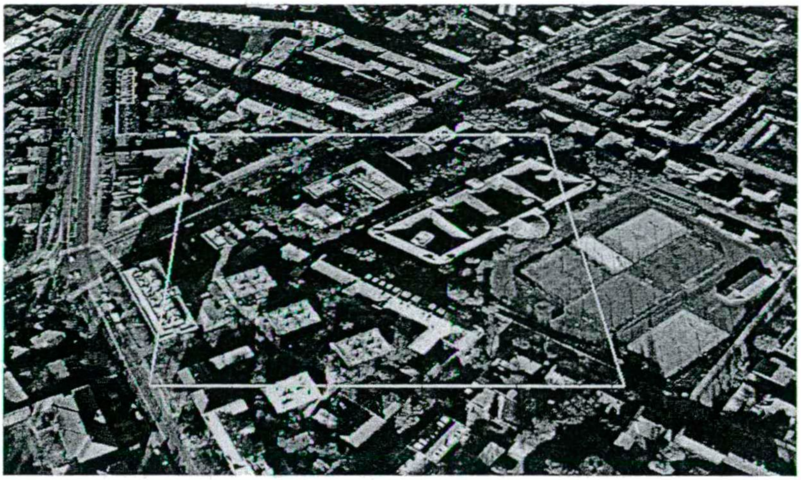


Fig. 2 3D view created by ERDAS IMAGINE of the investigated area

PET is a popular and useful bioclimatic index, because it has a widely known unit (°C) as an indicator of thermal stress. It makes results easy understandable and comprehensible for potential users who are not familiar with modern human-biometeorological terminology, including planners, decision-makers, and even the public. It evaluates the thermal conditions in a physiologically significant manner (*Matzarakis et al.,* 1999). PET is defined as the air temperature at which the human energy budget for the assumed indoor conditions is balanced by the same skin temperature and sweat rate as under the actual complex outdoor conditions to be assessed. This way PET enables various users to compare the integral effects of complex thermal conditions outside with their own experience indoors. In addition PET can be used all year around and in different climates (e.g. *Mayer and Matzarakis,* 1998a; *Höppe,* 1999). Meteorological parameters influencing the human energy balance include air temperature, air humidity, wind speed and short- and longwave radiation. It is necessary to determine these parameters at a human-biometeorologically significant height of 1.1 m above ground, corresponding to the average height of a standing adult's centre of gravity (*Mayer and Höppe*, 1987; *Matzarakis et al.,* 1999).

Large differences between air temperature and T_{mrt} (and PET) arise in winter days with high wind speed and in summer under calm and sunny conditions (*Höppe,* 1999). In these cases extreme cold or heat stress can be experienced. Examples of the resulting PET values at different seasonal, shading and wind conditions are illustrated in *Table 1*.

Investigations based on the application of PET in urban environments and their results are concentrated primarily on Germany (e.g. *Mayer and Höppe*, 1987; *Matzarakis et al.*, 1999; *Matzarakis et al.*, 2000; *Matzarakis*, 2002; *Mayer et al.*, 2004) and Sweden (e.g. *Svensson and Eliasson*, 2002; *Svensson et al.*, 2003; *Thorsson et al.*, 2004). Our work can contribute to this important research field and to the familiarisation with the usefulness of PET.

In this study we use T_{mrt} and PET to characterize the radiation conditions and to evaluate the human bioclimatological comfort sensations, respectively, in nearby, but different urban environments.

Table 1 Examples of PET values at different weather conditions (air temperature T_a, mean radiant temperature T_{mrt}, wind speed WS, vapour pressure VP) (*Höppe*, 1999)

Examples	T_a (°C)	T_{mrt} (°C)	WS (ms^{-1})	VP (hPa)	PET (°C)
Winter, sunny	-5	40	0.5	2	10
Winter, shade	-5	-5	5.0	2	-13
Summer, sunny	30	60	1.0	21	43
Summer, shade	30	30	1.0	21	29

2.3. RayMan model

One of the recently used radiation and bioclimate models is RayMan, developed in the Meteorological Institute, University of Freiburg. It is well-suited to calculate radiation fluxes [e.g. *Mayer and Höppe*, 1987; *Matzarakis*, 2002) thus all our calculations for T_{mrt} and PET were performed with this model. The RayMan model, developed according to Guideline 3787 of the German Engineering Society (*VDI*, 1998), calculates the radiation flux within urban structures on the basis of parameters such as air temperature, air humidity, degree of cloud cover, time of day and year, albedo of the surrounding surfaces and their solid-angle proportions.

The main advantage of the RayMan is that it facilitates the reliable determination of the microclimatological modifications of different urban environments, since the model takes into account the radiation modification effects of the complex surface structure (buildings, trees) very precisely. Besides the meteorological parameters the model requires input data on surface morphological conditions of the study area and on personal parameters.

Morphological-geometrical data

The co-ordinates of the building plane area were derived from a very detailed digital map of the Szeged Municipality, while the heights of the buildings were measured on digital orthophotos (compiled from aerial photographs) using the ERDAS IMAGINE software (*Fig. 2*).

Tree vegetation in the sample area was also mapped. Altogether, it includes 184 deciduous trees and the measuring points are shaded mainly by lime trees (*Tilia platyphyllos*). (The most effective and human-bioclimatologically significant radiation modification can be obtained by deciduous trees, because they can provide shade in summer, while in winter they hardly affect the irradiation, which can improve the comfort sensation at this time of the year.) The exact locations, heights, trunk heights, trunk diameters and canopy diameters of the trees are input data for the model.

Meteorological data

As input meteorological data for the model we use four measured parameters in both cases: air temperature T_a (°C), relative humidity RH (%), wind speed WS (ms^{-1}) and global radiation GR (Wm^{-2}). The detailed microclimatic monitoring was taken by a portable mini-weather station (type HWI) equipped with Campbell sensors according to the WMO standards and a digital data logger. The measurements were taken at a height of 1.1 m above ground.

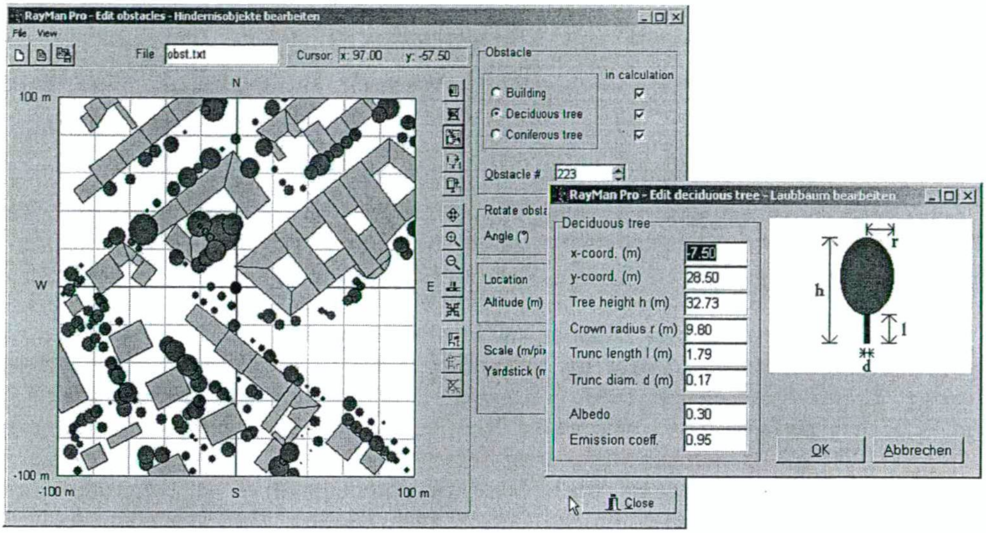


Fig. 3 The map created by the RayMan with the exact locations of the elements and the parameters of trees (buildings are marked by light grey and trees by dark grey)

Personal data

Concerning themo-physiology of the human body, the age, sex, height, weight, clothing insulation (in *clo* unit (e.g. *Mayer and Höppe*, 1987; *Yan and Oliver*, 1996)), physical activity and position (sitting or standing) of the investigated person have been considered. The comfort estimation in both cases is directed on an "average European male" (35-year old, 1.75 m tall, weight 75 kg). His clothing index of 0.9 clo corresponds to a long sweater and trousers as well as the heat produced by activity (metabolic heat) that is equivalent to 80 W (*VDI*, 1998).

Besides the calculated T_{mrt} and PET values, we also obtained graphical results as additional model outputs. Among others, the model compiles a picture from the 3D surface morphological data in polar co-ordinates of the area (similar to a fish-eye photo) including the visible part(s) of the sun path of the observation day at the place, with the contours of buildings, trees or other obstacles. It is helpful for the evaluation of the radiation conditions of the observational point. (Conversely, if we took a photo by fish-eye lens camera, it could be an input parameter.)

3. RESULTS

3.1. Weather situation

On the investigated day (6th August, 2003) the weather was calm anticyclonal in the region of Szeged. Since wind data are measured at a higher level (30 m, on the roof), the input data need to be recalculated. The wind speed is determined in the reference height of 1.1 m according to the next formula (*Kuttler*, 1998):

$$WS_{1.1} = WS_h*(1.1/h)^{\alpha} \qquad \alpha = 0.12*z_0 + 0.18$$

where WS_h is the wind speed (ms^{-1}) at the height of h, α is an empirical exponent, depending on the surface roughness, z_0 is the roughness length. In our case $\alpha = 0.42$, because the sample area and its surroundings are a densely built-up inner city area with trees (*see Fig. 2*).

In the sample area six measurement points were positioned, which are adjacent to each other, but are characterised by very different exposure and radiation conditions (*Fig. 4*). We endeavoured to represent the varied microclimatic conditions in this small sample area. Measuring points 1 and 2 were located in the northern part of the NE-SW positioned Egyetem street, where they were surrounded by high buildings. At site 1 the trees' foliage is nearly continuous, while at site 2 the distances between trees are larger and trees do not provide complete shading. Sites 3 and 4 are situated in the two sides of the NW-SE directed Batthyány street. The buildings are much lower and, therefore, the exposure to direct radiation is longer during the day. Point 5 was on the northern side of Petőfi avenue, in a relatively open area, while point 6 was on the southern side of the avenue. At site 6 the nearly completely closed canopy shades the place nearly all day.

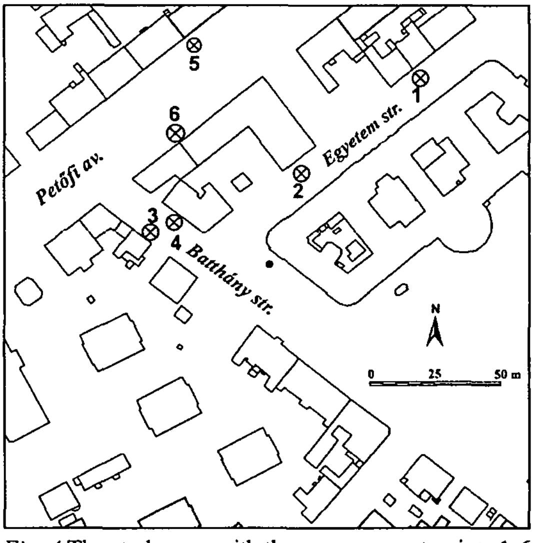


Fig. 4 The study area with the measurement points 1-6

List of the expositions of the measuring points:
- 1: street canyon with trees in NE-SW direction (abbreviated ***NE-scwt***),
- 2: street canyon without trees in NE-SW direction (***NE-scwot***),
- 3: street canyon with trees in NW-SE direction (***NW-scwt***),
- 4: street canyon without trees in NW-SE direction (***NW-scwot***),
- 5: wide street without trees in NE-SW direction (***NE-wswot***),
- 6: wide street with trees in NE-SW direction (***NE-wswt***).

The radiation characteristic of the investigated day is presented by the data measured on the roof (*Fig. 5*). The mobile measuring unit at the street level –due to its low sensitivity – demonstrated almost windless conditions all day. Therefore, *Fig. 5* shows wind data measured at a level of 30 m and the recalculated data for the height of 1.1 m.

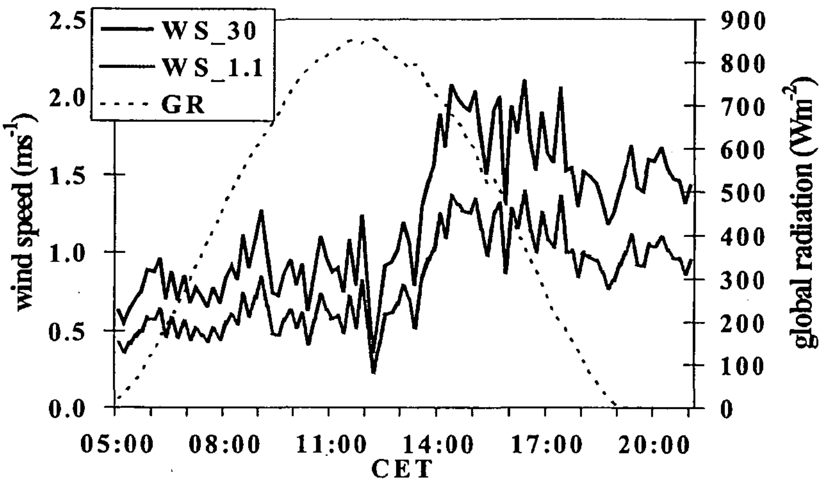


Fig. 5 Diurnal courses of meteorological parameters on 6th August, 2003 (WS_{30}: wind speed at a height of 30 m, $WS_{1.1}$: wind speed at a height of 1.1 m, GR: global radiation on the roof)

One minute averages were recorded by using the mobile measuring unit from sunrise till sunset. Temperature and relative humidity data recorded at the six points describe the weather characteristics of the day (*Fig. 6*).

The temperature values are identical (23.3-23.5°C) in every measurement points at sunrise and increase during the day due to the clear anticyclonal weather (*Fig. 6A*). The shape of the curves is similar during the day, the largest difference is observable in early afternoon, but the highest difference is only 1.7°C between the sites ***NE-scwt*** and ***NE-wswt.*** A short-time appearance of some clouds caused slight temperature decrease of a few tenth °C around 16.00 h. In the late afternoon until sunset the values converge. The relative humidity values are also identical in the six measurement points, the shape of the curves are the opposite compared to the temperature curves (*Fig. 6B*). Similarly to the temperature values, small differences between the sites can be seen; the slight increasing effect of the clouds in the afternoon is discernible. The small differences can be explained by the short distances between the measuring points.

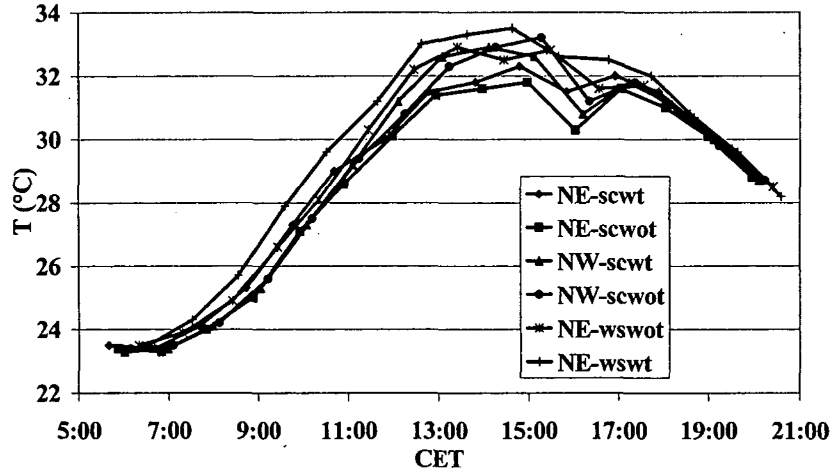
3.2. Thermal comfort

The calculated T_{mrt} and PET values obtained from the mobile measurements are shown in *Fig. 7*. In contrast to the weather data, the values for the selected sites show significant differences. The results show a remarkable spatial variability in the values of T_{mrt} and PET.

T_{mrt} values are low during the day at the points ***NE-scwt*** and ***NE-wswt,*** because trees and buildings prevent the direct radiation (*Fig. 7A*). The widest range can be observed amongst the values obtained at the site ***NE-scwt***. The value of global radiation (as well as the T_{mrt} value) increases immediately after sunrise and peaks at 13.00 hours. In the afternoon, an adjacent tree shades the site so that the global radiation declines after 13 h. High global radiation values are also measured at site ***NE-scwot,*** but the high buildings in close proximity give shade to the site and cause shorter irradiation (between 11.00 and

14.00 hours); therefore the radiation values quickly increase and then decrease there. At the site *NW-scwt* significant global radiation is measured only during a few hours in the afternoon.

A



B

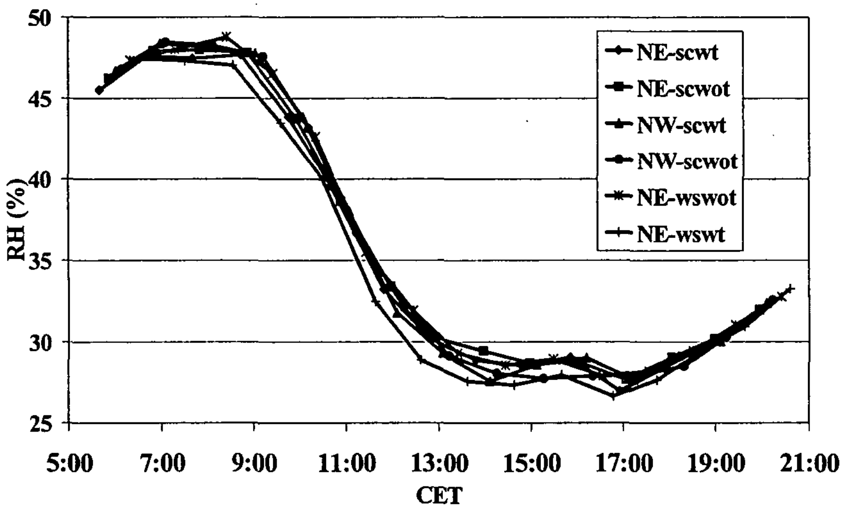
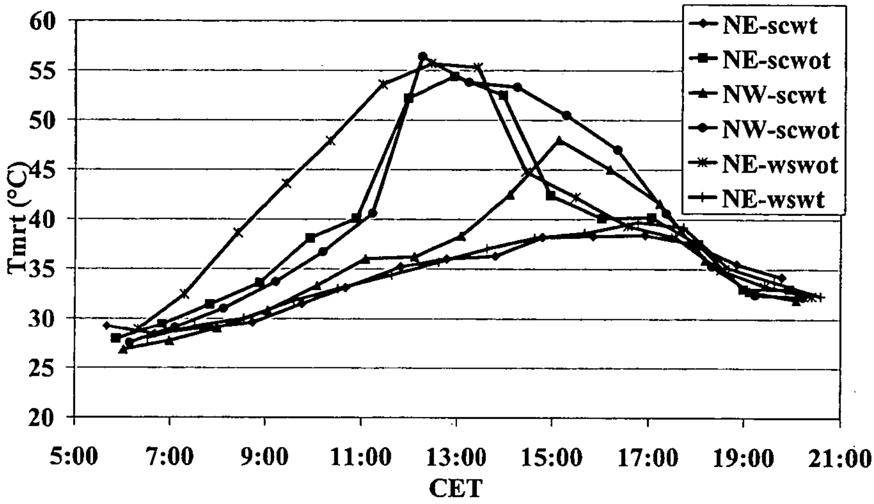


Fig. 6 Air temperature T (A) and relative humidity RH (B) at a height of 1.1 m above surface on 6th August, 2003

A



B

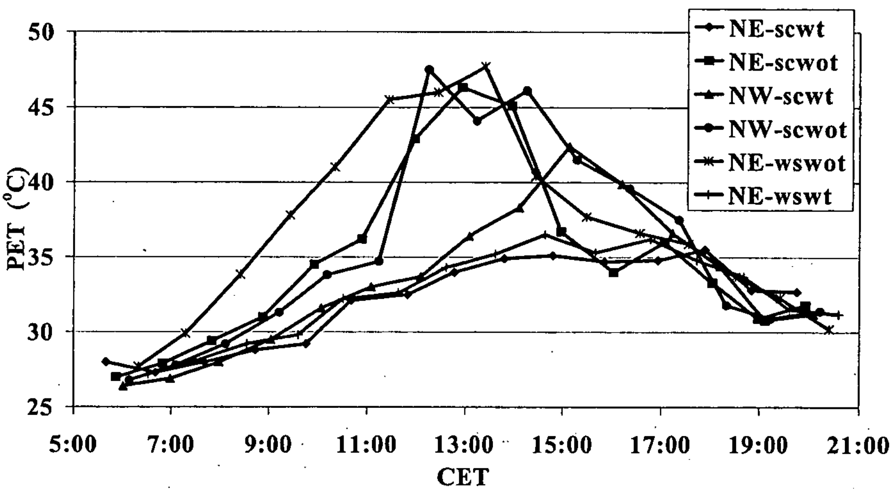


Fig. 7 Mean radiation temperature T_{mrt} (A) and Physiological Equivalent Temperature PET (B) computed by RayMan at the six measurement sites on 6th August, 2003

The calculated PET index shows that the heat stress exceeds the *comfortable* (18°C < PET < 23°C) level of human comfort (according to *Matzarakis and Mayer* (1996)) sensation during the whole day, a slight stress can be experienced even after sunrise (*Fig. 7B*). The heat stress is increasing until about 14.00 hours at every site, but local differences occur between the stations. The highest heat load is calculated for the site *NE-wswot* (PET = 47.7°C). This means an extreme physiological heat stress for the human body. The calculated maximum PET value reaches 45°C at the more open site *NE-scwot*, but the duration of the harmful effect of heat stress is shorter that at the site *NE-wswot*, due to the above-mentioned fast decrease of T_{mrt}.

The heat stress values are much lower on the sites (***NE-scwt*** and ***NE-wswt***) where no or only small amounts of direct radiation reach our model body. To present this, data from two measuring points ***NE-wswot*** and ***NE-wswt,*** which are close to each other (25 m) on the opposite sides of the same street (see *Fig. 5*), are compared. The fisheye views at these sites, generated by RayMan, show the path of the sun on the measurement day and the shading effect of the adjacent natural and artificial objects (trees, buildings) (*Fig. 8*).

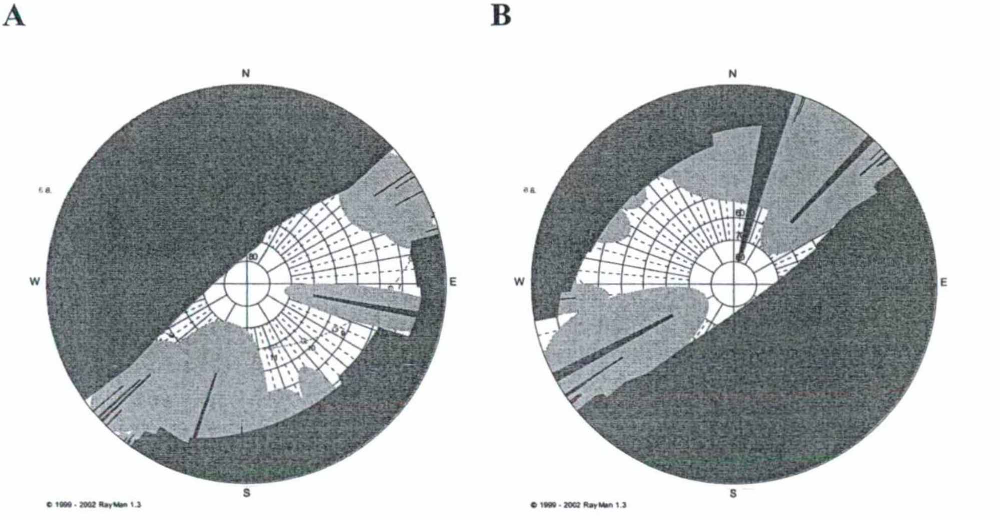


Fig. 8 Fisheye views at the measuring points ***NE-wswot*** (A) and ***NE-wswt*** (B) with the sun path on 6th August, 2003 created by RayMan

The measuring point ***NE-wswot*** is surrounded by buildings from NW, causing shade in the late afternoon (*Fig. 8A*). There is no coverage by buildings from other directions. In the first half of the day, only the tree canopies can provide some protection against the direct radiation. The opened SE exposure explains the extremely high direct radiation values and, as a result, the calculated very high heat stress. The point ***NE-wswt*** is in shade almost during the whole day (*Fig. 8B*).

Fig. 9 compares the T_a, T_{mrt} and PET values obtained from sites ***NE-wswot*** and ***NE-wswt***. The differences between the pairs are negligible at sunrise. The temperature values show small differences during the day, but between the T_{mrt} values the difference is increasing rather fast until early afternoon hours. As a result, the difference in the PET index at this time is very high (18-20°C), indicating a 2 step-stronger heat stress at the site ***NE-wswot*** than at the site ***NE-wswt***.

The study suggests that the value of the bioclimatic index PET – expressing the heat-load of the body – shows a strong correlation with the T_{mrt} value (the irradiation) in summer. This relationship is stronger than the relationship of the air temperature with PET. This statement is supported by the differences observed between T_a, T_{mrt} and PET values of the two selected points (***NE-wswot*** and ***NE-wswt***) in the second case. Despite the slightly higher temperature values at point ***NE-wswt,*** due to the irradiation conditions, the heat-load is significantly lower than at point ***NE-wswot*** (*Table 2*).

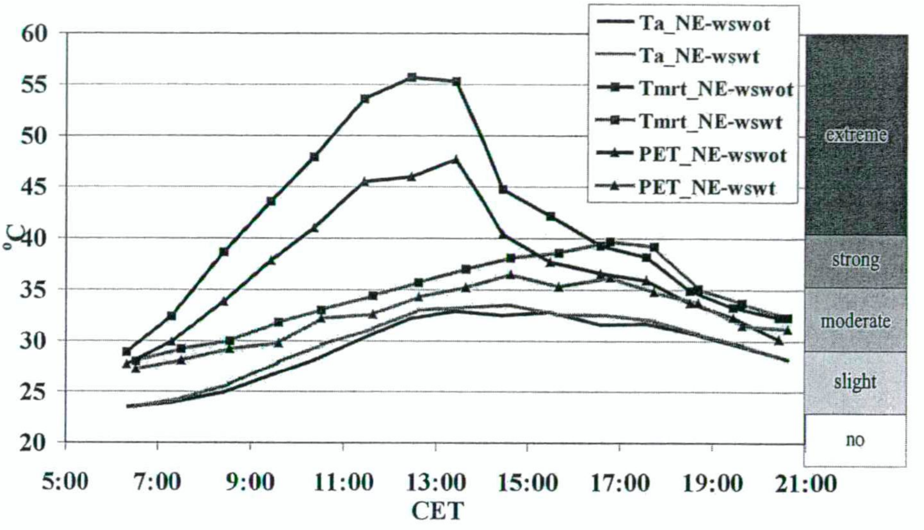


Fig. 9 Air temperature (T_a), mean radiation temperature (T_{mrt}) and PET with the Grade of Physiological Stress at the points ***NE-wswot*** and ***NE-wswt*** on 6th August, 2003

4. DISCUSSION

Table 2 Mean and maximum differences (°C) between the points ***NE-wswot*** and ***NE-wswt*** in the air temperature (T_a), mean radiant temperature (T_{mrt}) and Physiological Equivalent Temperature (PET) on 6th August, 2003

	point ***NE-wswot*** – point ***NE-wswt***	
	mean	*max*
T_a	-0.5	-0.6
T_{mrt}	7.0	16.0
PET	4.6	11.2

It is difficult for urban planners to design comfortable urban environments in cities or districts similar to our study area, because the parameters of the local climate are modified predominantly by the radiation modification effect of the 3D geometry of the existing built-up area. This phenomenon is more pronounced during summer when, after the high radiation load during daytime, the blocking or hampering of the outgoing long-wave radiation causes the heat island phenomenon, which often does not allow to decrease the heat stress to the *comfortable* level even during the night. Our results prove the beneficial effect of the vegetation, especially of trees.

Similarly to earlier studies in Germany, our results show a strong correlation between radiation modifications and changes in the thermal stress, focusing on the role of tree vegetation in these processes (*Mayer and Höppe*, 1987; *Mayer and Matzarakis*, 1998b).

An excellent prevention of summer heat-load is to plant deciduous trees. In our case the large canopy gives some protection against the direct radiation and, as a consequence, against the extreme heat stress in the midday hours. During the winter season the ideal situation is just the opposite (*Thorsson et al.*, 2004). Leafless trees reduce the extreme cold stress, since the incoming radiation with low angle can reach the surface unhampered.

The latest results of human bioclimatology and urban climatology should be considered when designing or reconstructing urban areas. Bioclimatic research can provide important data for planning and constructing urban surface structures and their environment, which is relevant not only for human comfort aspects.

5. CONCLUSIONS

The following conclusions are derived from the analysis presented:

- The presence of natural and artificial obstacles around the human body has an impact on the radiation fluxes and, consequently, on the energy balance of the human body; therefore changes in the radiation situation cause changes in the thermal comfort sensation.
- Complex urban environments can result in very different and often extreme comfort sensations even within short distances.
- The results obtained by RayMan can be a valuable source of information for planners, decision-makers and practitioners when planning and constructing new urban areas. The outputs are also of interest to the broader public, as they affect daily life.

Acknowledgement - The author wishes to give special thanks to L. Lakatos (University of Debrecen) for providing the mobile measuring unit and Z. Sümeghy and T. Gál (University of Szeged) for digital mapping.

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20[TH] CENTURY VARIATIONS OF THE SOIL MOISTURE CONTENT IN EAST-HUNGARY

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Összefoglalás - A jelen tanulmány az első szerző PhD dolgozatának Téziseit[1] tartalmazza, néhány főbb eredményt ábrákon és táblázatokban illusztrálva. A Tézisek célja, hogy megbízható, hálózatszerű meteorológiai méréseken alapuló, korszerű klimatográfiai elemzést adjon a térség változatos hidrometeorológiai viszonyairól, amely egyszerre tér ki az évközi változékonyság pontszerű statisztikai jellemzőire és a hozzáférhető talajnedvesség térbeli és időbeli kapcsolódásaira, valamint a hosszabb távú változásokra és azoknak a nagytérségű éghajlati trendekkel való esetleges kapcsolatára. Vizsgálataink zömét öt kelet-magyarországi meteorológiai állomás: Miskolc, Nyíregyháza, Debrecen, Kecskemét és Szeged 1901 és 1999 közötti, Palmer-féle Aszály-szigorúsági Index (PDSI) adatsoraira végeztük el. A térbeli kapcsolatok elemzéséhez 17 állomás 1951 és 1992 közötti PDSI sorát állítottuk elő, ezúttal a Thornthwaite féle növény-független módszerrel, a nem-homogenizált kiindulási adatokból. Munkánk további célja, hogy a vizsgált térség nedvesség-anomáliáin alapuló objektív regionalizálással; objektív évtípusok jellemzőinek és kalendáriumának közreadásával; valamint számos éghajlati szempontból reprezentatív hosszúságú, száraz és nedves időszak kijelölésével segítse a talaj nedvességkészlete által befolyásolt agro-ökológiai problémák további tudományközi vizsgálatát.

Summary - The present study is an illustrated version of the Abstract of a PhD Theses prepared by the first author at the University of Szeged[1]. The aim of the Theses is to give a modern climatographical analysis on the varied hydrometeorological relations of the region, based on reliable observations of meteorological stations. The analysis includes statistical characteristics of the inter-annual variability, spatial and temporal correlation of the available soil moisture content and long-range changes, as well as their possible relation with climatic trends for greater regions. The above-mentioned aims are intended to be realised on the basis of the *Palmer's Drought Severity Index* (PDSI) data series. Monthly PDSI data series of five stations (Miskolc, Nyíregyháza, Debrecen, Kecskemét and Szeged) were determined for the 20th century, in three versions. To study the spatial correlations short PDSI sets of 17 stations were calculated for the period between 1951 and 1992, with Thornthwaite's plant-independent method and without homogenisation. The objective and results of our work is to help further the inter-disciplinary study of agro-ecological problems, influenced by the soil moisture content, by performing objective regionalization based on soil moisture anomalies in the region; by publishing the characteristics and the calendar of the objective year-types; and also by determining climatically representative, long dry and wet periods.

Key words: Palmer's Drought Severity Index (PDSI), soil moisture content, time and space correlations, factor analysis, objective year-types, long term climate variations, method of "slices", Makra test

[1] This Abstract and the scientific record of Sz. Horváth resulted in winning the "Young Scientist Award" conferred to her by the European Meteorological Society (EMS) in 2004.

INTRODUCTION

Hungary and the eastern part of the Great Hungarian Plain have always been characterised by significant hydrological extremities. Drought and inundation events followed each other, sometimes even within a year. On the other hand, couple of decades proved to be either dry or wet during the 20th century.

The most serious inundation events occurred between the years 1939-1942 and extended over 5700 km^2. The whole area threatened by inundation exceeds 18,000 km^2, which reaches nearly 60 % of the cultivated lands of the Great Hungarian Plain (*Pálfai*, 2000). Considering the 20th century, droughts at the beginning and the middle of the 1900s, as well as those in the early 1990s were the strongest ones. Furthermore, the drought of similar strength in 2000 can also be listed here. Frequency of drought and inundation events are similar in the Great Plain (total area: 45,000 km^2, cultivated lands: 32,000 km^2); however, the typical spatial extension of the former phenomenon is much larger than that of the inundation (*Pálfai*, 2000).

The aim of the study is to give a modern climatographical analysis on the varied hydrometeorological relations of the region, based on reliable observations of meteorological stations. The analysis includes statistical characteristics of the inter-annual variability, spatial and temporal correlations of the available soil moisture content and long-range changes, as well as their possible relations with climatic trends for greater regions. The objective of our work is to help further the inter-disciplinary study of agro-ecological problems, influenced by the soil moisture content, by performing objective regionalization based on soil moisture anomalies in the region; by publishing the characteristics and the calendar of the objective year-types; and also by determining climatically representative, long dry and wet periods.

The above-mentioned aims are intended to be realised on the basis of Palmer's Drought Severity Index (PDSI) data series, known world-wide in agroclimatic analysis (*Palmer*, 1965; *Alley*, 1984; *Karl*, 1986; *Briffa et al.*, 1994; *Bussay and Szinell*, 1996; *Mika*, 1998; *Cook et al.*, 1999; *Domonkos et al.*, 2000). Monthly PDSI data series of five stations were determined for the 20th century (99 years), in three versions: a) plant-covered surface (maize) and homogenised (i.e. against possible non-representative peculiarities of the stations or the observations); b) bare (not plant-specific) surface, homogenised; and c) plant-covered surface, but non-homogenised meteorological data. Among them, we consequently consider the first alternative, i.e. the homogenised datasets for plant-covered surface as the most important, basic version. Analysis of the other two versions aimed to examine whether our conclusions could be influenced by the homogenisation and by any hidden features connected to evapotranspiration of the selected plant.

The following questions were answered in the study:

- Is the seasonal and spatial independence of the PDSI, elaborated for another region, valid in the Great Hungarian Plain, too?
- Can the distributions of the monthly PDSI sets be considered normal ones?
- Have the PDSI series got significant correlation to parallel independent estimations of the soil moisture content, according to which the index can be reliably interpreted as a soil moisture indicator?
- Do the PDSI anomalies show regional differences or definite structures in the examined region of Eastern Hungary (36,000 km^2)?

- Until what time-lag is the autocorrelation, coming from the recursive definition of the PDSI, significant, and what kind of year-types can be defined on the basis of the significant autocorrelation?
- What kind of slow changes occurred in the course of PDSI in the 20th century?
- Did these local changes show statistical connection to the synchronous temperature characteristics of the Northern Hemisphere?
- Did any sufficiently long periods, occur in the 20th century, of which the PDSI indices differed significantly from those of the whole period in the given month?

DATABASE

Most of our analysis was performed on the Palmer's Drought Severity Index datasets of five meteorological stations found in Eastern Hungary [Miskolc, Nyíregyháza, Debrecen, Kecskemét and Szeged] for the period between 1901 and 1999. The input data of the index consist of monthly mean temperatures and monthly precipitation totals. The datasets mentioned above are disturbed by inhomogeneity, so the homogenised monthly datasets were the basis of our calculations (*Szentimrey*, 1999).

The basis of the analysis is Palmer's Drought Severity Index, produced from the monthly temperature and precipitation datasets (*Palmer*, 1965). The PDSI was devised by its author for the climatic conditions of North-America, in order to develop a numerically defined index, which is partly independent from local and seasonal features, and which partly shows the extremities of the soil moisture content always and everywhere on the same scale. (Owing to the different climatic conditions, the examinations started with the questions of place- and season-independence and with interpretation of the PDSI as a parameter of the soil moisture content.)

The Palmer-index numerically defines the soil moisture anomalies of the given month in five steps, beginning from the PDSI value of the preceding month. This PDSI value is multiplied by 0.9 and added to a term which is proportional to the difference between the precipitation of the given month and the computed precipitation that could definitely keep the actual soil moisture conditions unchanged. The proportionality coefficient weighting this difference before it is added to the PDSI is a temperature-related empirical factor calculated for the climatic conditions of the USA.

The above-mentioned steps of the calculation are performed in order to determine the precipitation amount, which is needed for preserving the soil moisture content. The stages of this process are the calculation of the elements of the potential (maximal, if there is enough water content) water balance and then establishing multiplicative factors for making normalisation, against the differences of local and seasonal climates.

A crucial point of calculating the PDSI is the choice of the formula and the reference-plant to estimate the potential evapotranspiration, which is performed in two versions. The basic solution was to choose Blaney-Criddle's plant-specific procedure, by assuming maize on the soil. This plant is characteristic for our region, and its evapotranspiration is fairly similar to that of many other plants, due to its quickly extending leaf surface. As an alternative, Thornthwaite's plant-independent PDSI series, based on climatic calculations, were also taken into account (*Thornthwaite*, 1948; *Alley*, 1984).

Considering the five stations used for representation of the region, it did not seem important that the soil types differ. Hence, the water capacity of 150 mm was taken into account in all versions of PDSI computation (*Stefanovits,* 1975). The above-described computation of PDSI leads to a non-dimensional index, qualitatively related to humidity conditions.

For studying the spatial correlation, the five stations are not enough, of course. Consequently, short PDSI sets of 17 stations were calculated for the period between 1951 and 1992, with Thornthwaite's plant-independent method and, in proper sense, without homogenisation. Differences between the water capacities of the characteristic soil-types of the arable land were taken into consideration at these 17 stations.

Besides the PDSI, two further datasets estimating the soil moisture content were used, kindly provided by the authors. Both sets use various combinations of the daily meteorological elements, influencing the water balance of the surface. Monthly correlation coefficients between the monthly values of the two series are between 0.7-0.9 in most part of the year, while they are only between 0.4-0.7 from May to September. Dunkel's dataset (*Dunkel,* 1994) was used between the years 1901-1990, while that of Bussay (*Lambert et al.,* 1993) was applied between the years 1901-1988. These parallel series were used to certify the PDSI as a quantitative indicator of the soil moisture content, and to establish the conversion of the PDSI into the soil moisture, as a physical parameter.

Besides these parameters, a version of Pálfai's Drought Severity Index was produced and used, operating with the monthly temperature and precipitation data, without numerically defined corrections of the daily extremities (*Pálfai,* 1991). The author, himself also suggests it as the PAI_0 Index. This index is a favourable tool for agro-hydrological examinations, the only disadvantage of which is that each year is characterised by one number only, integrating the period from October to the following August. The PAI_0, as a further independent index, supports our conclusion that PDSI can really be related to the soil moisture content.

Finally, connections of PDSI to the global climatic anomalies were based on series of the hemispheric mean temperatures and the continent-ocean air temperature contrast (*Mika,* 1988), as derived from air temperatures above the continents and the oceans of the Northern Hemisphere (*Folland et al.,* 1984; *Jones et al.,* 2000).

METHODS

In the study, the classical uni- and multivariate methods of the mathematical statistics are applied. Firstly, the first and second momentums of the monthly PDSI sets are determined then the place- and season-independence of the latter ones are examined with F-test, pair by pair. (The averages differ from zero because the reference period is not the whole 99 years but only the first 80 ones.)

The monthly PDSI sets, amalgamating all months and stations in one sample, as it is known from the special literature, do not fit the normal distribution. When dividing the whole set into monthly subsets for the separate stations, their normality is improving, examined by the Kolmogorov-Smirnov and the χ^2 tests.

The spatial and temporal correlation coefficients, calculated for short datasets of 17 stations in the region, are all significant when using the Z-test. On the basis of these, objective regions are determined using the rotated factor analysis (*Horel,* 1981). The results are compared to the classification of the hierarchical cluster analysis based on the Ward-method, using the Euclidean distances. The cluster analysis is also applied for determining objective year-types utilising the significant temporal autocorrelation. However, in the latter case, the method of K-means (*Hair et al.*, 1998) is chosen to classify the years into three year-types as dry, medium and wet ones.

The smoothing for detection of slow changes in the long data series is performed by the traditional moving averages and by the Gauss-filter, which does not deform the effect of any intermediate frequencies. The calculation window was 11 years in both cases.

Finally 1-1 methods of the supervisors are applied, which do not exceed the field of the methods represented in the first sentence of the current chapter. The parameters of the local changes and the hemispheric temperature; namely the connections between the mean temperature in the Northern Hemisphere and the continent-ocean air temperature contrast are defined numerically by the method of "slices" (*Mika*, 1988).

The essence of the method is slicing the original datasets into sub-periods of the same length (5, 9, 13, 17 and 21 elements) and then, using the averages of the sub-periods, a regression analysis is performed.

The method of "slices" is applied to the datasets between 1901 and 1988 and the conservation of the coefficients is tested for the independent period of 1989-1999. The correlation between the two hemispheric variables is negligible in the basic period, which makes it possible to avoid the so-called "multi-collinearity" of the two independent variables. The regression coefficients are estimated by the method of the "least squares", while their statistical significance is checked with Student's t-test.

Both the investigation of the slow changes, and the regression analysis performed with the hemispheric temperature characteristics referred to the substantial changes in the values of the PDSI, parallel with the global warming, considering the 20th century. Hence, the closing chapter of the study aimed to select climatically representative long periods, which can be used for impact studies on any problems depending on the soil moisture content.

In order to identify dry or wet sub-periods, averages of which are significantly lower or higher than that of the whole 99-year long dataset, a new interpretation of the classical two-sample test (*Makra et al.*, 2000, 2002; *Tar et al.*, 2001) was performed. The basic question of this test is whether or not a significant difference can be found between the averages of an arbitrary sub-sample of a given time series and the whole sample.

The normality of the distribution of monthly PDSI, which is found to be valid only partially, is a satisfactory condition to the application of the method. At the same time this is not a necessary condition, since in case of very large samples (99-99 data) the distribution of the density function for the sum of the elements is nearly normal, apart from the distribution of the basic sample. Besides that, a further condition is that the random variables be independent, which is realised for the succeeding PDSI values.

Most of our analysis was carried out on the monthly PDSI datasets of the whole year, while a smaller part of it was conducted on the four selected months of the growing season (April, June, August and October). The odd months in the latter case were omitted considering the strong and significant autocorrelation.

RESULTS

In the first eight points the results are summarised, based on Palmer's Drought Severity Index datasets and calculated by the Blaney-Criddle method. Input data of this calculation are homogenised temperature and precipitation data series.

The differences of the PDSI data, generated by Thornthwaite's method of the potential evapotranspiration and homogenised data, from the above-mentioned sets are represented under point 9. On the other hand, the comparison of the PDSI based on partly homogenised, partly non-homogenised data, both calculated by Blaney-Criddle's method, can be found under point 10.

The results for the whole year are contained under points 1-5, while those for the growing season between April and October are found under points 6-8. Discussions of both points 9 and 10 follow this structure.

1. Place-independence of the PDSI, as a desirable condition, when elaborating the index for different climate conditions, is realised for the monthly values of the five stations in the Great Hungarian Plain. According to the F-test, the standard deviations of only one pair of stations differ significantly, which is far below the random proportion.
   Season-independence of PDSI, as another desirable feature, is only partly realised in the Great Plain, since the proportion of significantly different standard deviations is three times higher than that comes from pure chance. Standard deviation of the indices is considerably lower in May and June, than those of the other months. On the other hand, none of the standard deviations of the other ten months differ significantly from each other.
2. When putting the index values of i) the five stations, ii) the twelve months, iii) both aspects into one sample, the distributions of the PDSI differ significantly from the normal one in all of the three cases. The main reason of this result is the rare occurrence of the near-zero values, which is a well-known feature of the index, experienced in other regions as well. On the other hand, when analysing the PDSI sets of each station and month separately, then, according to the Kolmogorov-Smirnov test, distributions of all the 5 x 12 = 60 samples are normal. According to the χ^2-test, distributions of only ten samples are not normal at the 95 % probability level. This value (ten from the all sixty) is three times higher than the chance; nevertheless, the distribution of the samples for most stations and months can be considered normal.
3. The PDSI, as a standardised index without unit, has a close relation with the two (Dunkel's and Bussay's) calculations of the monthly soil moisture content, as well as with the Pálfai-index, characterising the water supply of the growing season from October to next August. According to this, the PDSI can correctly be interpreted as a characteristic of the soil moisture content. Furthermore, on the basis of the regression coefficients of linear connection, the index values can be expressed in physical unit of the water content of the upper 1 meter soil layer. Hence, the unit increase of PDSI corresponds to 8-19 mm surplus according to Dunkel's soil moisture estimates, and 5-17 mm surplus according to Bussay's one, depending also on season and place.
   Another feature of the regression coefficients, referring to the deep sense of the PDSI, is that if they are divided by the standard deviation of the soil moisture content, the following coefficients having no units result: 0.35 ± 0.05 in the datasets of the Dunkel's soil moisture content, while 0.25 ± 0.07 in those of Bussay's. Consequently, the unit change of the PDSI in each month and station equals to almost the same change in the unit of the soil moisture content standardised by the standard deviation.

4. The spatial correlation of the PDSI in each of the 15 station-pairs formed of the five stations and the 12 months exceeds the significance threshold value of 0.3 but does not reach the value of 0.9 in any case. From November to April all values are over 0.6, while from May to October they are lower than the winter values. In this period even the hydrological extremities of the region develop partly independently from each other.

   The significant spatial correlations makes it possible to determine objective sub-regions for the examined area. In the enlarged network with 17 stations, the rotated factor analysis of Thornthwaite's non-homogenised index series with shorter datasets results in at least two sub-regions in each month. The sub-regions are located along the north-east – south-west axis; whereas more stations and larger area belong to the southern sub-region. At the same time, during the seasonal alternation from drying out to filling up, between September and November, the procedure isolates an intermediate sub-region, too (*Horváth*, 2002; *Horváth et al.,* 2000). The independent method of the cluster analysis also confirmed the classification of the stations to the sub-regions received from the factor analysis.
5. The high autocorrelation, coming from the recursive definition of the PDSI, remains significant even at the time difference of two (0.7-0.9) and six months (0.3-0.7). Within these ranges, the somewhat lower values of the autocorrelations in the summer half-year come from the higher variability of convective precipitation.

   The high autocorrelations makes it possible to define so-called year-types objectively. The twelve months from November to the next October were classified into three types by cluster analysis. Each type occurred in a considerable part (14-57 %) of the 98 examined years. At all stations 1-1 year-type can be isolated, each month of which is definitely dryer or wetter than the average. At three stations, each month of the third type is around the average, while this type is characterised by a wet summer after a dry winter at Miskolc and Debrecen. The knowledge of the fact that a given month of a given year fell into which year-type, reduces the monthly variance of the PDSI with somewhat more than 50 %, as an average (*Horváth*, 2002). Proportion of the year-types differs from one decade to the other, in relation with the long-term changes of PDSI.
6. The PDSI datasets, calculated for the even months of the growing season, show significant linear trends only at three stations in April in the whole period of the 99 years. At the same time, the trends for each month and station are negative. Considering a hundred year time-span, its values are -0.7 and -3.1, respectively. Namely, the 20th century was characterised by slow drying out. This definite tendency is reflected also in the datasets, smoothed with the moving average and Gaussian filters, detecting the non-monotonous and non-linear details of the slow inter-annual fluctuation.
7. The search for regression connection between the PDSI datasets and the average temperature and the continent-ocean temperature contrast of the northern hemisphere yields significant connection with at least one of the latter variables for 80 % of all months and stations, in the growing season. Most coefficients, relating to the hemispheric temperature, are negative. Namely, the drying out in the basic period between the years 1901-1988 is connected not only with the time, but the warming characterising the average of the northern hemisphere, too.

   The partial regression coefficients relating to the continent-ocean contrast (the rate of the warming) are mostly negative as well. The significant coefficients calculated for a hemispheric warming of 0.5°C involve a decrease between -0.5 and -2.9 in the values of the PDSI, if the connection can generally be related to other periods, too. At the same time, this assumption is not supported by the behaviour of PDSI in the following independent 11 years (1989-1999), when the agreement of the actual PDSI anomalies and those calculated with the regression is not better than the chance (*Horváth*, 2002).

8. The break-point analysis makes it possible to detect sub-periods, PDSI averages of which differ significantly from that of the examined 99 years. Considering the growing season, the length of these significant sub-periods is many decades in most of the examined months and stations. The maximum difference of the sub-period's averages from that of the whole dataset decreases according to an exponential function, as the length of the sub-period increases. There are a number of sub-periods characterised by significant deviation from the overall mean being higher than the unit of the PDSI. Significant wet sub-periods are detected in the first half of the 20th century, while dry breaks occurred in the second half of the century. The averages of significant sub-periods with opposite signs show even more definite difference, than those between one-sided deviations and the overall mean (*Horváth, et al.*, 2000; *Horváth, et al.*, 2001; *Makra et al.*, 2002).

DISCUSSION

Main results concerned the PDSI values computed by the Blaney-Criddle method of potential evapotranspiration by using homogenised data. Here we discuss the behaviour of PDSI based on two alternatives, following the structure of the previous chapter.

The difference of the homogenised PDSI dataset, based on Thornthwaite's potential evapotranspiration from that calculated with the Blaney-Criddle method, are generally not substantial, but they can be summarised as follows:

i) The standard deviations in each month are somewhat higher than those determined assuming plants. There is no significant difference between the standard deviations of the month-pairs even including May and June.

ii) Distributions consisting of the largest datasets (5 stations*12 months*99 years; 5 stations, separately, 12 months*99 years) differ significantly from the normal distribution. Most monthly distributions per stations can be considered normal; nevertheless, the number of those monthly datasets, the distributions of which are not normal, is definitely higher than the chance.

iii) The strong linear connections between these PDSI datasets and the soil moisture content are to some extent weaker in most part of the year; though in May and June they are stronger.

iv) Most spatial correlation coefficients are higher than those determined by considering plants.

v) Most of the temporal correlation coefficients are higher than those determined by considering plants.

vi) The linear trends for the whole period decrease more intensely and the drying out according to the smoothed curves is steeper in this version. In other words, existence of plants slightly reduced the drying-out in the 20th century.

vii) The regressions relating to the hemispheric temperature are mostly negative in this version, too. The significant coefficients refer to a drying out higher than 20 %.

viii) The limits (the starting and the ending years) of the significant sub-periods are not independent of the method of calculating the PDSI. The ratio of the concurrently significant sub-periods in both versions is very little. Hence, before the possible application, it is worth to choose with care which method of PDSI to use for identification of the analogous periods.

The difference of the indices, using the Blaney-Criddle method and non-homogenous data series, from the above-mentioned basic behaviour are generally not substantial, but they can be characterised as follows:

i) There is no important difference compared with the results for the standard deviations of the homogenised dataset.

ii) The distributions consisting of the largest datasets differ significantly from the normal one in this case, too. Most of the monthly distributions per stations can be considered normal; nevertheless, the number of those monthly datasets the distribution of which is not normal is definitely higher than the chance in this case as well.

iii) The correlation coefficients between these PDSI datasets and the soil moisture content are stronger in this version, probably because this latter estimation is also performed on non-homogenised data.

iv) Most of the spatial correlation coefficients are lower than those calculated for the homogenised datasets.

v) Most of the temporal correlation coefficients are somewhat lower than those calculated for the homogenised datasets. The given homogenisation does not lead to considerable changes in centres of the year-types.

vi) Linear trends for the whole period decrease to a lesser extent and the drying out, according to the smoothed curves is also slighter in this version. In other words, the given homogenisation increased the drying-out characterising the 20th century.

vii) Regressions relating to the hemispheric temperature are mostly negative in this version, as well. However, the significant coefficients refer to a drying out lower than 20 %. Hence, the homogenisation increased the drying out in this respect, too.

viii) Limits (the starting and the ending years) of the significant sub-periods are influenced by the homogenisation. The ratio of the concurrently significant sub-periods in both versions is very little. Hence, before the possible application, it is worth to choose with care which method of PDSI to use for identification of the analogous periods.

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WINE AND LAND USE IN NAGYMAROS, NORTHERN HUNGARY: A CASE STUDY FROM THE DANUBE BEND

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Összefoglalás – A tanulmányban a szőlőtermesztésnek a tájhasználatban s annak változásaiban betöltött szerepét vizsgáljuk, különös tekintettel a szőlőművelés által érintett területek térbeli kiterjedésére, melyek részben az erózió által amúgy is veszélyeztett meredek déli lejtőkön helyezkedtek el. Habár a szőlőtermelés elsőrendű fontosságát általában már legkésőbb a 14. század elejétől nyomon követhetjük, a szőlőnek a tájban betöltött szerepére vonatkozó első közvetlen leírás a 16. század elejére datálható. A 16. század végétől a 17. század végéig tartó visszaesést a 18. század elejétől a szőlőterületek még feltehetően a késő-középkorinál is nagyobb mértékű kiterjesztése követte, különösen a déli lejtőkön, egészen a csúcs-régiókig. A 19. század végétől a filoxéra és más betegségek illetve egyéb, gazdasági és társadalmi folyamatok hatására mára a szőlő gazdasági jelentőségét és egykori, tájképet meghatározó szerepét teljesen elvesztette. A szőlő húzóágazat szerepét előbb a gyümölcs- és szőlőtermesztés, majd az egyre jelentősebb méreteket öltő turizmus vette át, míg az egykor a tájképet meghatározó, kiterjedt szőlőművelésre már csak a közben visszaerdősült, helyenként meredek déli hegyoldalak felső régióinak pusztuló kősorai és teraszai utalnak.

Summary – In this study, the possible impacts of wine cultivation on landscape and land-use changes in Nagymaros is discussed with special consideration on the spatial extension of cultivation in the area of the endangered steep southern hillslopes of former vine cultivation. Primary importance of wine production can be proved from early 14th centuries, but the first direct evidence for the description of extensive vineyards in the landscape comes from the early 16th century. Decline can be detected from the late 16th century to the late 17th and early 18th centuries. By the end of the 18th century, vineyards in southern top-hill regions reached probably their greatest extent. Caused by the phyloxera disease, greatest landscape changes occurred at the end of the 19th century when hill-slope vineyards were almost entirely destroyed. Due to diseases and several other, mainly socio-economic reasons, wine production today has minor or practically no importance while other functions, such as fruit and grape production and then tourism, had growing impact on the landscape, while traces of former cultivation were destroyed or are still lying hidden on the reforested hillslopes.

Key words: vine cultivation, landscape change, hill vineyards

STUDYING THE CHANGES OF ABANDONNED VINEYARDS

While in Western Europe, the great expansion of agriculture (and thus, forest clearance) mainly ended up with the late 13th century, 14th-15th centuries were probably the most active periods in Hungary. It is approximately from the 13th century when in the hilly areas of Hungary vine cultivation largerly extended on the slopes of favourable exposure. Before this time, vine cultivation more frequently appeared on plains and lowlands or even inundation areas. This 'new' method, however, needed much more and qualified labour as lowland production, though wine became more tasty than it was before (*Égető*, 1980). Wine production in '*promontoria*' (hill vineyards) was predominant in Hungary until the collapse of viticulture occurred in the late 19th century primarily due to the phyloxera disease (*Beck*, 2003).

The reason of modern decline, however, can be traced back to several reasons. After the late 19th-century collapse and desertion, vine was reinvented in many areas, but vine cultivation started to'slip' down to the 'skirt', namely to the pediment area of hills (e.g. *Pintér*, 1988-1989; *Laposa,* 1999; etc.). This situation became even more predominant after the collectivization process of the 1950s and the creation of cooperatives, since the less steep areas could be cultivated by machines which made cheap mass wine production possible. This 'progress', nevertheless, resulted a great increase in quantity but decrease in quality, while the formerly better-quality areas of highly-terraced '*promontoria*' were mainly abandonned and reforested (see e.g. *Laposa*, 1999). However, abandonment from the 19th century (even before phyloxera appeared in Europe) was already rather general not only in Hungary but also in other parts of Europe with intensive hill-cultivations, such as in the Mediterranean areas (e.g. *Dunjó et al.*, 2003. 24).

These intensively cultivated areas are also important since today there are only few places where steep slopes with relatively high elevation (over 250 m) are cultivated in the country. Nowadays, most of the vineyards in Hungary are located between 100-200 m above sea level (see e.g. *Kriszten*, 1999. 23, 30-37). Nevertheless, in the historical wine region of Tokaj-Hegyalja, for example, the optimal uppermost level of quality wine production is around 300-350, but sometimes even 400 m on slopes with southern exposure. *Justyák* (1965. 35), studying the microclimatic conditions of the southern slope of the Nagy-Kopasz Hill in Tokaj, has proved that the annual mean temperature starts decreasing more rapidly only from around 350 m above sea level. Cultivation of these higher slopes are also more favourable in general, due to the fact that early and late frosts have less effect here than in lower areas (e.g. *Boros*, 1996. 54). In Hungary, vineyards abandonned at the end of the 19th or during the 20th centuries were studied both by geographers, local historians and ethnographers: these examinations were mainly related to vegetation changes and the historical geography of certain areas, such as the one in the Balaton Uplands (e.g. *Pátkay and Sági*, 1971; *Laposa,* 1988, 1988-1989, 1999; etc.), in the area of Pomáz-Szentendre-Leányfalu north to Budapest (*Baráth,* 1963), as well as in the historical wine regions of Tokaj-Hegyalja (*Balassa*, 1991; *Boros*, 1996. 73; *Nyizsalovszki*, 2001. etc.), Sopron (*Kücsán*, 1999; etc.), the surroundings of Pécs (*Erdősi*, 1987), the Mátra Hills (*Bodnár*, 1987), and Hungary in general (see e.g. *Pintér*, 1989; *Csoma*, 1997; etc.).

Unlike other wine regions with several hundred years of continuous cultivation, the small wine region of the Danube Bend practically ceased to exist after the phyloxera disease even if at the beginning of the 20th century tremendous efforts were made to restore former vineyards and the significance of wine production. As a result, the landscape of the area changed fundamentally and thus, large part of the formerly-cultivated slopes, up to the top, was reforested. Since this phenomenon, as we could see, was also wide-spread in other wine regions of the country, the landscape changes of former '*promontoria*' of Nagymaros as well as the intensity of cultivation together with possible former erosion and the protection against this erosion can be used later as a parallel while reconstructing conditions of other areas of formerly intensive (vine) cultivation.

LOCATION AND PHYSICAL CONDITIONS

Nagymaros, located in the Danube Bend approximately 50 km north to Budapest (see *Fig. 1*), is part of the temperately warm climatic region with predominant influence of the ocean. This can be also characterised by temperately dry, mild winters (B. V. 9) and an annual precipitation of 600 mm (*Mersich*, 2003. 35). The average amount of sunshine is between 1850-1900 hours per year. This is somewhat more than that of Tokaj-Hegyalja (1800-1850 hours per year), but less than, for example, in such other traditional wine regions as the Balaton Uplands and the Villányi Hills.

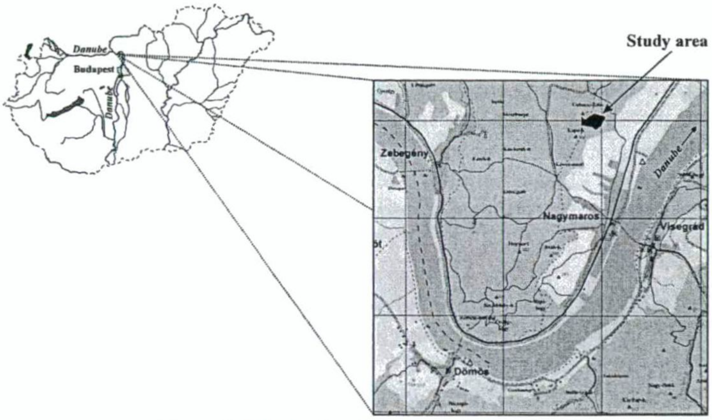

Fig. 1 The Danube Bend and Nagymaros

The '*promontoria*' of Nagymaros were located on the southern slopes of hills characterised by Miocen andesite partly covered by a soft, thin layer of limestone. The predominant soil type is brown forest soil with clay illuviation, but arubase and stony soils can also be found in the area, all well suitable for wine production. Terraces of natural origin (fluvial Danube terraces) also appear on these southern slopes (*Pécsi*, 1991. 36-47). It was mainly the hills along the Danube with southern exposure which were all, up to the end of the 19th century, utilized as vineyards. As the southern edge of the Börzsöny Hills, the former '*promontoria*' are today situated in the close vicinity of the Danube-Ipoly National Park.

VITICULTURE AND LANDSCAPE BEFORE THE 18TH CENTURY

The history of vine cultivation in the area of Nagymaros cannot be separated from that of the Danube Bend in general. While in the heydays of wine production in the second half of the 18th to the late 19th century the town of Vác was a main wine producer along the eastern side of the Danube north to Buda and Pest, grapes and wine had primary importance in the more northerly villages (e.g. Kismaros, Verőce, Zebegény) and towns (e.g. Nagymaros, Visegrád), located in the Danube Bend. Nevertheless, among the wine producing settlements of the Danube Bend, the town of Nagymaros was probably the most important. Thus, any of the landscape transformations taken place due to changes in vine cultivation in Nagymaros are quite representative for the changes occurred in the entire Danube Bend in general. Although many of the early aspects of wine and fruit production in Nagymaros have been discussed by some authors (see e.g. *Jakus*, 1991. 17; *Mándli*, 1994. 175-178; etc.), here an overview and some new information had to be included due to the fact that these early sources provide at the moment the only (though indirect) evidence to the question in what extent certain intensive land-use types affected the landscape and soils of the area for a longer period of time (several hundreds of years).

The name of the rapidly growing settlement appeared in a charted dated to 1255, when the king annexed a land in Maros to his own properties (*Knauz and Dedek*, Vol. 1, 1874. 430; *Györffy*, 1998. 272-273). By the end of the 13th century, the settlement was bought up by the king, and was entitled as a royal '*villa*' in 1297 together with its wine and grain tithes, amongst others (*Knauz and Dedek*, Vol. 2, 1882. 399). Its importance in trade can be detected in the great number of Viennese pottery found at excavation sites in the historical centre of the settlement (*Torma*, 1993. 218-219). Another significant information on the former landscape conditions of the town can be found in the donation charter of king Charles I dated to 1324 (*Knauz and Dedek*, Vol. 3, 1924. 47). In this document, among the most important (re)sources of the town, vine cultivation is highlighted. In 1326, one fourth of the town's wine- and one third of grain tithes were awarded to the parish priest (*Knauz and Dedek*, Vol. 3, 1924. 75-76). At latest from the 14th century, Nagymaros comprised a single economy with the royal centre and summer residence of Visegrád, opposite side of the Danube, supplying the town as well as the royal palace complex with agricultural products (*Magyar*, 1998. 23). According to the early 18th-century description of Matthias Bél, chestnut was also planted at that time, in the early 14th century (*Szabó*, 1977. 160).

In his book, issued in 1536, Nicolaus Oláh found vineyards as the most important, characteristic features of the landscape in Nagymaros. Here the archbishop describes the view of the early 16th-century Nagymaros as was seen more than a decade before, from a window in the upper-castle of Visegrád: „... *in the area lying on the other side of the Danube, the oppidum of Nagymaros, inhabited by German settlers, is located; above* (the settlement) *an extensive not too high hill arises, planted with vinestocks all over.*" (translated after the crit. ed. *Eperjessy and Juhász*, 1938. 16). His remark is especially important because it gives a clear proof that in the early 16th century at least the hill nearby the settlement (Fehér hill) was heavily involved in vine cultivation, and this was the most characteristic cultivated landscape feature worth mentioning about Nagymaros. At this time wine production, according to *Szakály* (1995. 227-228), acted as the most important economic branch of the settlement, since the yearly production of Nagymaros was around 30-40,000 hectoliter in the early 16th century. The former great importance of wine production can also be detected by the great number of wine celars located all around the town centre and beyond, in many cases with early-modern or perhaps late-medieval origin (*Torma*, 1993; *Zsoldos*, 2001. 121). Since Nagymaros has only a narrow plain along the Danube, sometimes anyway inundated by the river, this large amount of wine could be mainly produced on the slopes. Thus, even if except for the short description of the archbishop we have no direct medieval evidence concerning the landscape characteristics of the hills, it seems quite obvious that some of the hills or at least the Fehér hill described by Oláh above, were covered by vineyards already in the late Middle Ages. Naturally, the extent of this intensively cultivated hilly area and other questions such as the possible impact of intensive cultivation, level of erosion and protection techniques applied are all yet unkown, although with the help of late medieval as well as early modern parallels some rough estimations can presumably be drawn in the future.

In the first decades of Turkish occupation, according to the conscriptions of the sandsak (Turkish district) of Buda, between 1546 and 1562 must and wine production became more than double in Nagymaros (*Káldy-Nagy*, 1985. 424; *Jakus*, 1991. 17). Beyond their own territories, the inhabitants of Nagymaros had vineyards, even in the politically difficult decade of the 1540s, for example, in Kisoroszi, while the inhabitants of

Kisoroszi also possessed vineyards in the territory of Nagymaros (*Káldy-Nagy,* 1971. 73; *Káldy-Nagy,* 1977. 253; *Szakály,* 1995. 240). Although the ownership of the area changed several times which caused a great devastation of the area, the settlement still stayed inhabited and continued vine cultivation as an important branch of their economy up to the end of the Turkish occupation in 1686. Paying taxes both to the Habsburgs and the Turks, wines of Nagymaros and related problems are mentioned in conscriptions, petitions and other sources in several cases (see e.g. *Mándli,* 1994. 179-180). Even if the number of inhabitants sharply decreased by the 1580s (*Káldy-Nagy,* 1985. 423; *Szakály,* 1995. 234-236), the greatest abandonment of vineyards and '*promontoria*' presumably occurred during the fifteen-year war (1591-1606): by 1612, according to the petitions of the inhabitants, only one third and by 1630 less than one fourth of the formerly cultivated vineyards remained (*Jakus,* 1991. 17; after MOL, E 41, 5/2. No. 31, 149). In 1631, inhabitants could pay only smaller tax due to their poorness and the fact the vine hills did not 'give' enough already for a long time (*Jakus,* 1991. 67; MOL, E 213, Hont: Fol. 76/6).

The first known pictoral representations of Nagymaros are strongly related to the siege of Visegrád in 1595. On some of the contemporary copperplates (thought to be reliable) the lower sections and the pediments of hills, but sometimes also the higher parts of southern slopes are covered by lonely trees which can symbolize woodland as well as underwood vegetation with only some few trees around (*Szalai,* 2001. 40, 143, Table 231: 1597 – OSZK-TK, App. H. 612, and Table 232: 1597 – OSZK-TK, Ant. 217). Referring to the other important war-period of the 1680s the northeastern hills of Nagymaros with southern exposure, in this case again – either with real or symbolised meaning – only some trees scattered on the bare landscape, were depicted (*Szalai,* 2001. Table 235: 1686 – OSZK-TK, 123473).

In conclusion, a primary significance of wine production presumably with some earlier roots can be detected from the 14-15th centuries extending up to the second half of the 16th century. Although we have only one direct contemporary source, indirect evidence suggests a great spatial expansion of vineyards in the landscape. From the second half of the 16th century a gradual decline started and continued throughout the 17th century, although vine cultivation even in this problematic period played a significant role in the economy of the settlement. This shows clear parallels to many other areas where vine cultivation had large importance. Unlike in many parts of Western Europe where climate change had major impact on wine production, the instabile political conditions and (Turkish) wars of the 16th and 17th centuries can be more blamed for the temporal decline (*Égető,* 1999). Nevertheless, after Turkish wars ended up in the majority of the country in the late 17th century, a new, probably even greater second expansion started in the first half of the 18th century.

A NEW EXPANSION OF VINE: THE 18TH CENTURY AND BEYOND

Much more is known from the late 17th, but especially from the early 18th century when Nagymaros, as part of the Visegrád-estate, became a royal property again. More than a decade after expelling Turks from the area, still half of the formerly cultivated vineyards lay fallow in 1699 (MOL, UC 87: 69). Throughout the first half of the 18th century, predominantly German-speaking settlers of different locations (e.g. Germany and Austria) arrived in small groups and in several 'waves', rather than once in a large community (*Magyar,* 1998. 62, 82) – probably also inventing some of their own cultivation practices in their new home area. In Nagymaros, the ownership period of the Austrian Stahremberg family (1700-1756) resulted prosperity and a probably greater expansion of cultivated lands on southern slopes than ever before. From the beginning of the 18th century the most significant parts of the estate, namely large portion of forests and woodlands, most of the vineyards, arable lands and industrial buildings e.g. the new brewery and the brick-works, were located in Nagymaros (*Magyar*, 1998. 102, 108, 111, 114).

As a reference to the ongoing vine-stock planting campaign, the incomes of the young manorial vinestocks are mentioned in 1749 (MOL, UC 74: 8). In 1766, another source already points to the division between the 'old' vines and the 'new' vines in Nagymaros (MOL, UC 142: 12). In the same time a great increase of vine cultivation can be detected which was subsidized by the estate (see e.g. 1754 – MOL, O 18. Fol. 21-22/1430). Vineyards of the settlement extended to 1558 1/2 hoes at that time (e.g. 1766 – MOL, UC 142: 18; 1776 – 142: 13). The inhabitants of the town also made spirit out of the vine which was not imposed to any taxation (1766 – MOL, UC 142: 14, 142: 18); moreover, beyond some further taxation, they could sell their own wine and vineyards without any control. One of the most significant incomes of inhabitants came at that time from pubs and inns (1776 – MOL, UC 142: 13). The wines of Nagymaros had better price than that of Visegrád: while Nagymaros wines cost 1 Ft 75 denar, Visegrád wines were worth for 1 Ft 25 denar per urn (*Magyar*, 1998. 108, 112; see also 1749-1753 – MOL, UC 74/8).

All the above-mentioned information on the great greatest extent of vineyards on slopes of southern-southeastern exposure is supported by the map of the First Military Survey (*Fig. 2*) and the detailed late 18th-century estate map of Nagymaros (1787-1805 – MOL, S11. 207/b) describing the land use of the area: vineyards extended almost up to the top of the hills with southern exposure.

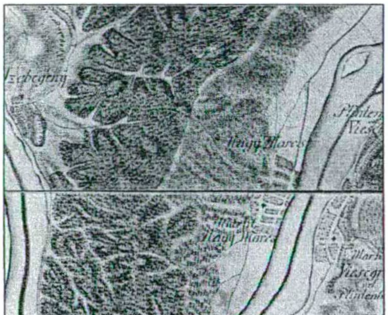

Fig. 2 Map of the First Military Survey (1784) – HMT, Coll. XII. Sec. 17-18 (original: M 1:28,800)

Concerning wine production, another important issue is that in the second half of the 18th century Nagymaros was an important junction of roads leading from the north to the south, as the trading route from Moravia reached and crossed the Danube at Nagymaros, through the Börzsöny Hills. In the second half of the 18th century, wines of Nagymaros were mainly exported to the north, for example, to the mining town of Selmecbánya (today Banská Štiavnica in Slovakia) which caused a great prosperity for the town and real peak of wine production (*Magyar*, 1989. 143-145). In the second half of the 18th century vineyards were probably more important elements of the Nagymaros landscape than ever before. This last information becomes especially interesting if we consider the fact that the second half of the 18th century was already the beginning of a long-term decline (due to lost markets) in the two traditionally most export-oriented historical wine regions of the late 16th-17th centuries: Tokaj-Hegyalja and Sopron (see e.g. *Kücsán*, 1999; *Nyizsalovszki*, 2001. 86).

At the end of the 18th century, the 'kind taste of wines' of Nagymaros is especially emphasised in the description of *Vályi* (1796. 581). Still a primary significance of wine, but growing importance of fruit (including chestnut) can be detected in the early and mid-19th-century sources (1845, 1857-1859 – MOL, UC 249/40, 43). In the 1820s, for example, chestnut trees were (partly) located among the vineyards, in the *'promontoria'* area (1826-1827 – MOL, UC 249/41). According to the description of *Pesty* (1986. 226-227) and *Fényes* (1985. 70), good-quality (white) wines, fruits and chestnut were produced here around the mid-19th century. In 1870, the hills of the settlement were characterised by chestnut forests while extensive vineyards could be found on the slopes which, according to *Nagy* (1870. 154), provided medium-quality wines. In 1873, approximatelly 90% of the wines produced were white (KSH, 1986. 13).

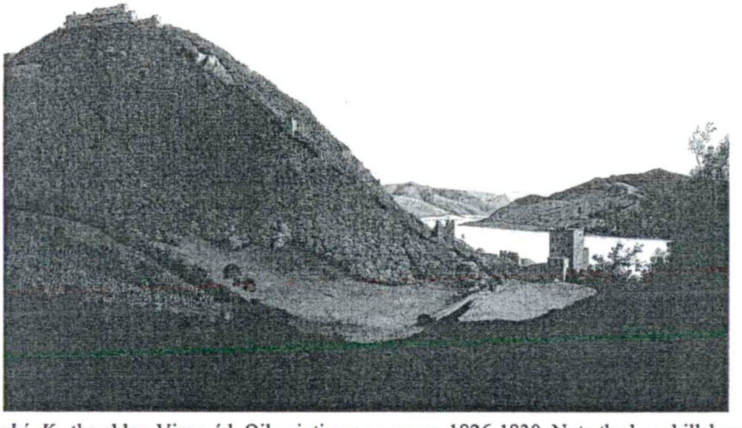

Fig. 3 Markó, K., the elder: Visegrád. Oil painting on canvas, 1826-1830. Note the bare hillslope over the Danube, at the other side

Referring to the 19th century, on the spatial extent of utilization probably the best sources are maps and landscape paintings. While the late 18th-century maps, mentioned above, gave us a detailed picture on the extent of vineyards in the landscape, concerning map evidence little is known up to 1850s: the cadaster map of 1856 approximately the same extent of "*promontoria*" can be detected then at the beginning of the century (OSZK-TK, Bv 1455/1/1-2). The relevant map of the Third Military Survey (1872-1873 – HMT 4862/3), although considerably more trees appeared among the vineyards, still shows no significant difference in land use to the situation described in the late 18th century. An excellent extra source provides more information on the 'dark' decades: on the detailed, topographically realistic paintings of *K. Markó* the elder, entitled '*Visegrád*' (1826-1830; see *Fig. 3*), the bare hills above Nagymaros, cultivated up to the very top regions, can be seen clearly. Same is the case with those other 19th-century realistic-romantic pictures where the landscape of Nagymaros or parts of it is clearly visible: although in a bit of a romantic context and contours, according to the mid-19th-century drawing of *L. Rohbock* (published in *Hunfalvy*, 1859. 220) cultivation on the southern slopes extended up to the top region. The information found in contemporary pictoral evidence, thus, supports the data derived from other contemporary sources.

COLLAPSE AND NEW PROSPERITY: LANDSCAPE CHANGES FROM THE LATE 19TH CENTURY

Up to the end of the 19th century, the settlement mainly produced grapes (and wine), chestnut and walnut (*Döbrössy*, 2004. 67). Especially phyloxera (1875-1895), but in some extent also peronospora (1893-1895) diseases at the end of the 19th century, similar to other historic wine regions of Hungary (see *Beck*, 2003), devastated most of the vinestocks in and around Nagymaros from 1886 (*Mándli*, 1994. 196; see also *Döbrössy*, 2004. 69): a fact which clearly appears in the dramatic fall of areas under vine cultivation (*Fig. 4*). Whatever great the devastation of vineyards was, a rapid replantation campaign started; around the turn of the 19th and the 20th centuries not only fruits and chestnut, but also dessert grapes were exported to the markets of Vienna and Budapest, while good-quality wine was produced and sold (*Borovszky*, 1911. 59; *Döbrössy*, 2004. 68).

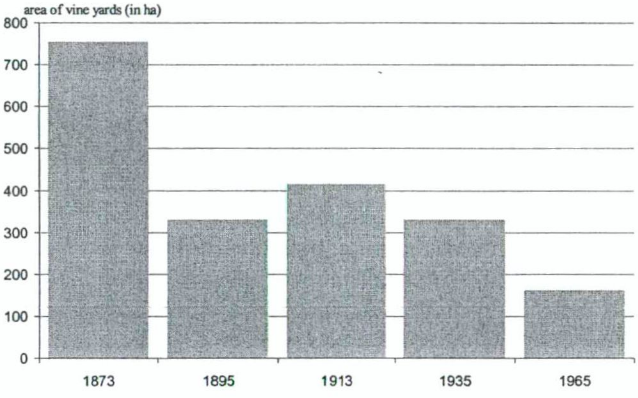

Fig. 4 Changes in the extent of Nagymaros vineyards from the late 19th century (KSH, 1986. 64)

Although in the first decades of the 20th century the settlement was one of the centres of new vine (re-)plantations in the country, in 1932 vineyards occupied less than 10 % of Nagymaros lands (PMU: V. 1079 c, d). What is more, even if one of the main regional centres of the countrywide replantation campaign was Nagymaros (*Beck*, 2003. 343), these plantations usually had much less effect on the high slopes of former terraces any more. The great amount of fruit trees at the turn of the 19th and 20th centuries, and later the significance of raspberry (especially from the 1920s and 1930s) are emphasised in many sources, which fruits – together with vine grapes – were exported mainly to Vienna and Pest, but also to such more remote destinations as, for example, the Czech Lands, Germany and Russia (for more details, see *Mándli*, 1994. 185-187, 190-192). Thus, fruit production (e.g. redcurrant, raspberry, apricot, peach, plum but also chestnut and walnut), gained much more importance up to the end of the 1930s (see *Döbrössy,* 2004).

Located relatively close to Budapest, in the second half of the 19th century, after direct train connection was established between Pest and Nagymaros in 1851 (see e.g. *Mándli*, 1994. 184), the Danube Bend became a favourised holiday destination (*Borovszky*, 1911. 59) – a role continuously increasing today. From this time, Nagymaros was a popular holiday destination mainly due to the picturesque view of the Visegrád Hills and the Danube Bend in general, together with the magnificent ruins of the former royal castle-complex. After the Second World War, but especially from the 1960s onwards – similar to what happenned in other former hill vineyards, for example, at Lake Balaton (e.g. *Laposa*, 1988. 35-40) – a growing amount of cottages and family houses occupied the formerly cultivated lands on the southern hillslopes, in many cases already reaching the reforested lands of former vineyards. Due to its importance in tourism, the changing landscape of the slopes can be also detected on contemporary postcards, from the late 19th century (e.g. OSZK-PKNyT, Postcards/Nagymaros: from 1891).

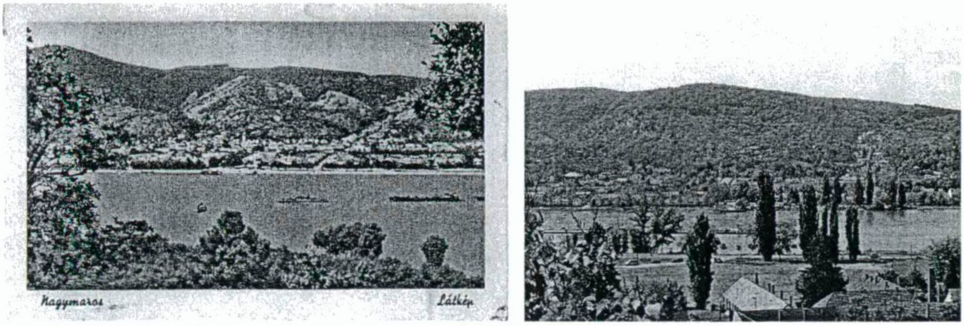

Fig. 5 The Nagymaros landscape (with the Fehér Hill in centre) on postcard in the late 1940s and on a photo taken in June, 2005 (private properties of the first author). Note the changes especially visible on the Fehér Hill (in the middle of both photos)

From the late 1940s and in the 1950s great changes occurred in the agriculture due to the new policy in economy, then the collectivisation and mechanization which, similarly to many other parts of the country, resulted the final abandonment of southern hillslopes being too expensive and labour-demanding for large-scale farming. The process of abandonment in the former '*promontoria*' clearly appears, both on maps (*Fig. 6*) and other pictoral sources such as aerial photos or postcards (see e.g. *Fig. 5*), even if vineyards in many cases were replaced with other cultivation types (orchards, chestnut forests, meadows, etc.). Thus, probably the greatest changes and the final abandonment of the higher and steep southern slopes occurred from the 1950s on, although this was already preceded by a process of gradual decline.

OUTLOOK

As far as the spatial extension of viticulture is concerned, the most active periods of vine cultivation in Nagymaros were the 14th-early 16th and, after a period of a relative decline, the 18-19th centuries; quite in the same time when, for example, in the South-German hilly areas probably the greatest soil erosion of the last Millenium were detected, namely to the 14th, 18th and 19th centuries (see e.g. *Bork et al.*, 1998; *Dotterweich et al.*, 2003).

It seems clear that in the early 16th century the latest, some of the hills (or at least one) in the close neighbourhood of the town were permanently and entirely used for vine cultivation, and afterwards, even in the worst periods of the 17th century, wine kept its primary importance among the other incomes of the settlement. Probably the ever largest spatial expansion of viticulture occurred in the 18th century due to systematic and subsidised clearance and vinestock plantations; by the end of the century practically all of the slopes with favourable exposure, almost up to the top level of hills were covered by vinestocks. Compared to other important wine regions, modern declines did not occur in the same time: while in case of Tokaj-Hegyalja and Sopron a gradual decrease started already in the second half of the 18th century, wine production of Nagymaros reached its probably ever greatest extent in the same period. Although the increase of fruit production (similar to vine, with intensive and erosive cultivation) can be also detected, vine presumably kept its primary importance up to the end of the 19th century.

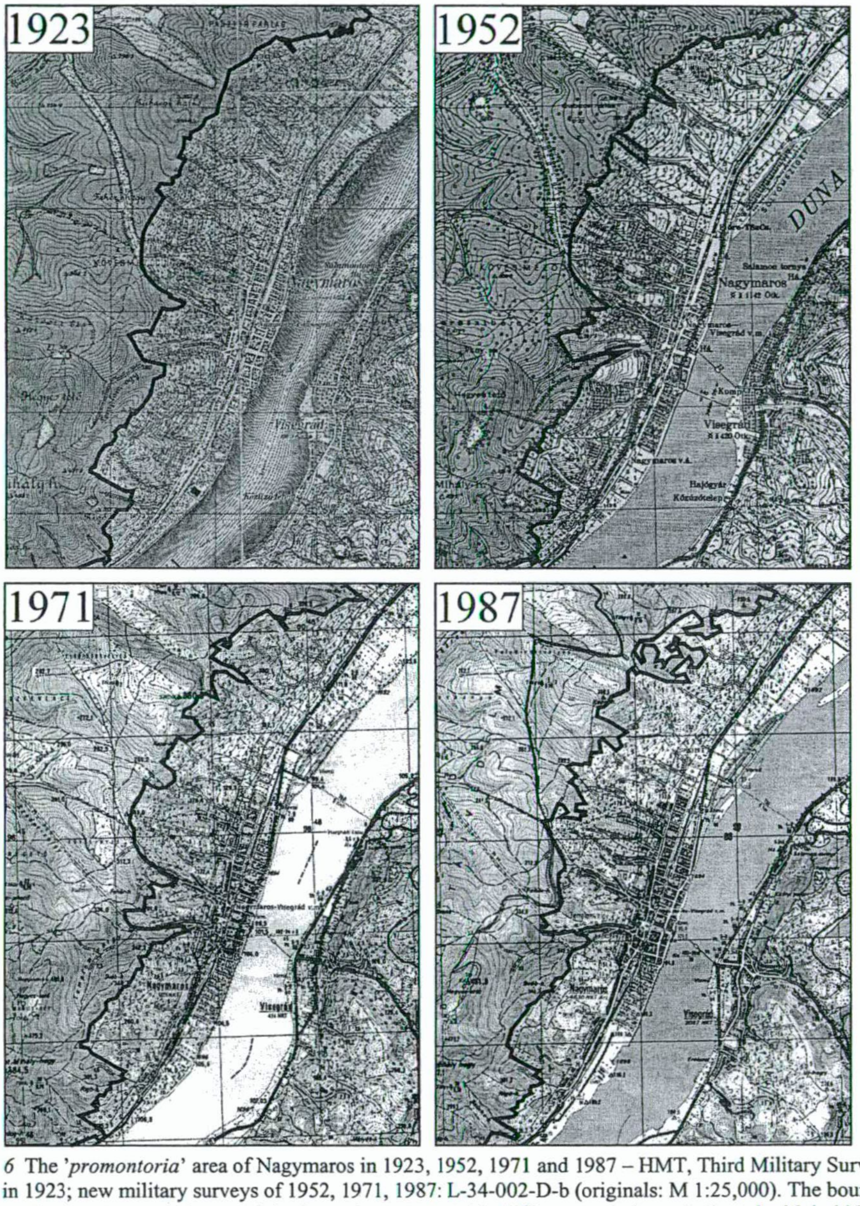

Fig. 6 The '*promontoria*' area of Nagymaros in 1923, 1952, 1971 and 1987 – HMT, Third Military Survey, revised in 1923; new military surveys of 1952, 1971, 1987: L-34-002-D-b (originals: M 1:25,000). The boundaries between the forest-area and zone of the fomer '*promontoria*' in different periods are indicated with bold lines. Note the decrease of '*promontoria*-zone' and the cultivation change taken place inside of the territories of '*promontoria*-zone'.

Thus, being intensively cultivated, some of the steep southern slopes of Nagymaros, turning towards the Danube, were subject to severe erosion for hundreds of years. Due to the application of various traditional techniques – whose traces (e.g. terraces, ditches) are still visible in the today highly-reforested landscape – however, in the time of intensive cultivation, soil erosion was certainly decreased in quite a large extent. In order to have a closer look on the former extent of human impact, more intensive and detailed investigations on present physical conditions were needed, for which a smaller study area with well-preserved man-made features was chosen, clearly referring to a longer period of former vine cultivation (see *Kiss et al.*, 2005).

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HISTORICAL LAND USE AND ANTHROPOGENIC FEATURES: A CASE STUDY FROM NAGYMAROS

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Összefoglalás – A tanulmányban egy körülbelül 0,15 km² kiterjedésű, korábban szőlővel borított, mára már részben visszaerdősült területet vizsgáltunk. A Kapu-hegyen elhelyezkedő mintaterületen viszonylag nagy méretű, épségben maradt kősorok, árkok és teraszok találhatók. A 18. század végén a terület délkeleti kitettségű, meredek hegyoldala döntően szőlőművelés alatt állt egészen 19. század végéig, de a terület művelése – részben megváltozott területhasználat mellett – gyakorlatilag az 1950-es évekig folytatódott. A hosszú időn keresztül folyt intenzív művelés és az erózió elleni védekezés az eredeti talaj szerkezetét erősen átalakította. Terepi vizsgálataink során bizonyos törvényszerűségek megállapításával s párhuzamok keresésével olyan kérdésekre próbálunk választ találni, mint például: mikor és miért kerültek oda s meddig voltak használatban a területen található kősorok, árkok és teraszok, illetve hogy az egykori intenzív használat nyomai milyen mértékben követhetők a jelenlegi felszínen és a talaj fizikai szerkezetében.

Summary – In this study, an approximately 0.15 km² representative study area of former vineyards, now partly reforested, is the subject of investigation. The area of the Kapu Hill is characterised by a system of relatively large and intact stone hedges, ditches as well as well-preserved traces of man-made stone and earth terraces. In the late 18th century this steep slope of southeastern exposure was predominantly covered by vineyards and thus, it was subject to severe erosion roughly until the late 19th century, but – with changed land use – in some extent until the 1950s. Due to intensive vine cultivation as well as effective protection techniques soil structure was strongly modified. In the course of our investigation we try to find out the main characteristics and probable regularities in the set of abandonned man-made features, seeking for the answer of such questions as when and why these stone hedges, ditches and terraces became part of the landscape and in what extent intensive land use left its marks on the present soil and surface of the study area.

Key words: hill vineyards, changed land use, historical soil protection, man-made features

THE STUDY AREA

The study area (between 340 and 220 m above sea level) is located northeast to the town of Nagymaros in the former '*promontoria*' (hill vineyards) area, on an 18-22° slope of the Kapu Hill with south-southeastern exposure, turning towards the Danube, under the plateau of the Gubacsi-hálás (360 m), at the boundaries of the Danube-Ipoly National Park (*Fig. 1*). It is surrounded by oak forest from the upper part of the slope, while a long supporting wall and a road close it down at the lower end, separating the study area from the today extensively utilized zone of cottage houses (former vineyards). At the two sides chestnut and oak forests are located. In between, our sample area of abandonned terraces, long stone hedges and stone-bedded ditches is mainly characterised by forest steppe and shrubby vegetation.

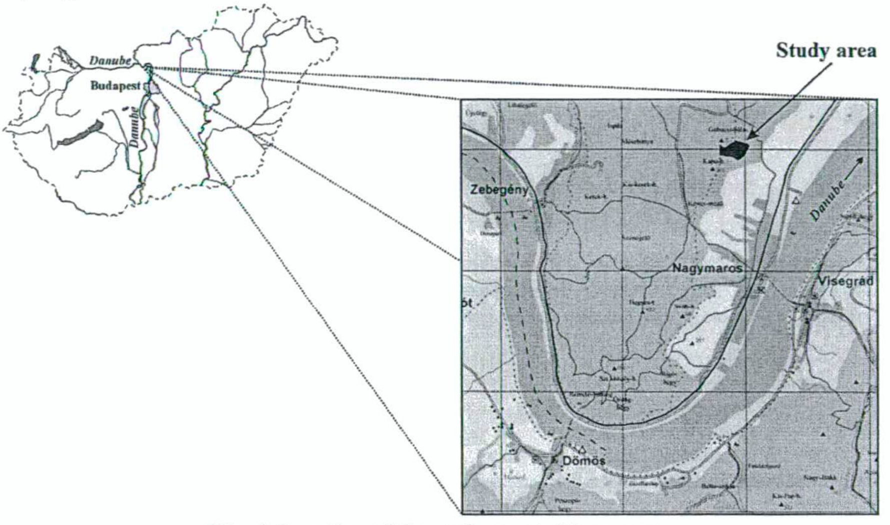

Fig. 1 Location of the study area in Nagymaros

The bedrock of the hillslope is Miocene andesite and andesite agglomerate, typical for the Börzsöny Hills, but in the eroded head part of the valley, located south-southwest, limestone as well can be found in patches (only in detrital form). Terraces of natural origin, namely fluvial Danube terraces, also appear in the study area (*Pécsi*, 1991. 36-47). The characteristic soil cover is the strongly eroded brown forest soil with clay illuviation, in plateau position black erubase soils, in the environment of the bare bedrock stony soils can be found, while black rendsinas also appear on limestone patches. The volcanic bedrock debris and the thin brown forest soil with clay illuviation as well as the black erubase and stony soils are acceptable for traditional vine cultivation, which needs a minimum soil depth of 30-40 cm, and another 1-3 m-deep permeable layer where roots can absorb nutriments (e.g. *Boros*, 1996. 10).

The study area is significant not only because of its terraces and long stone hedges, but also because it is located in a 'transitional' area: between the mostly forested upper-hill zone and the main areas of continous, traditional cultivation (fruits, arable, meadows, etc.) in the pediment area. Due to its distance from the historic centre (less than one hour on foot), the steepness of its slopes, the relatively high altitude as well as the favourable exposure, the study area is quite likely to be cultivated in periods of economic expansions. However, such an area always needs higher investment both in terms of labour and money, though presumably a better-quality wine can be produced as a result, especially compared to some less-favourable lands of the former Visegrád estate Nagymaros belonged to (e.g. vineyards of Visegrád, on the other side of the Danube). Beyond the risks mentioned above, another negative effect could be soil erosion in general.

Thus, the present examination has two main aims: one aim is to detect the former land use (cultivation types, techniques) with its *in situ* remains and some past structures still retraceable in the study area. Another aim is to provide a detailed field survey of the study area, utilizing the already-known information of previous land use, cultivation forms and some main characteristics of vegetation. In connection, among many others, it is an important question when, why and how man-made terraces, stone hedges and ditches were created, for how long these features were in use, and when, why and how they were finally abandonned. In order to find the adequate answers, beyond field examination of soil structure analysis and dendrochronological study, we used contemporary written documents, maps and some currently-published works of local history research as well as parallels, namely the results of geographical, botanical and ethnographical, historio-etnographical research of other areas mainly carried out in Hungary.

IMPORTANCE OF ABANDONNED TERRACES

The application of terraces in the more effective utilization and soil protection of hilly areas, namely in cereal as well as in vine- and fruit production was much more wide-spread in the last millenium until the late 19th century than it is today. In the international (especially the oversea) research is mostly concentrated on South-America, partly on the Asian subtropical areas and the European Mediterraneum (see e.g. *Spencer and Hale,* 1961; *Denevan*, 2001. 133-211; etc.; for Asia see e.g. *Xing-guang and Lin,* 1991; for European example see e.g. *Bell and Boardman,* 1992; *Rackham and Moody*, 1996; *Dotterweich et al.*, 2003; *Dunjó et al.*, 2003; etc.).

In Hungary, the largest number of terraces, still traceable, were built in connection with ploughing and vine (or fruit) cultivation. Among the research in connection with abandonned terraces, formerly used as ploughlands, one has to emphasize the importance of the works of Gyula Nováki. He studied the area of Nagybörzsöny and Bernecebaráti (Börzsöny Hills, north to Nagymaros), where abandonned ploughlands with long stone terraces were found, dated to a period prior to the 18th century (*Nováki*, 1975). Another investigation took place at the deserted late medieval settlement of Sarvaly (close to Sümeg, Western Hungary) as well as near Tamási in Tolna county, South-Hungary (*Nováki*, 1984). Moreover, historio-ethnographic research was carried out in the Hegyköz area (Northeast-Hungary) and the Palóc lands, in North Hungary (e.g. *Hoffmann,* 1956. 541, 543, 550, 554; *Balassa,* 2000. 57).

While terraces connected to ploughing activity are mainly characterised by few, but long (several 10 m) terraces, such intensive cultivations on steep slopes as vine are generally more connected to shorter terraces, although sometimes long terraces can also be connected to vine cultivation. Most of the abandonned terraces of former vine cultivation all around the country are said to be dated back to the 18th-19th centuries, but some of the features might be built already in the 17th century or even earlier (see e.g. *Balassa,* 1991. 76, 92-93. etc.). Application of terraces on steep slopes were wide-spread in vine cultivation until the late 19th century. As a branch of anthropogenic geomorphology, in Hungary mainly geographers studied the anthropogenic features and the extent of human impact occurred, among others, in (former) hill vineyards with terraces and other man-made features. A good conclusion of these works, especially for South and Southwest Hungary, were carried out by *Erdősi* (1984), referring to, for example, the wine regions of Szekszárd as well as the Villány and Mecsek Hills.

From our present viewpoint, historical parallels also have special importance. The most well-investigated example is Tokaj-Hegyalja: the preparatory works, namely the formation of stone hedges, land boundaries, terraces, ditches – at least from the early 17th century – were carried out by specialised skilled workers of German origin, living in the village of Mecenzéf in Northeastern Hungary (*Balassa*, 1959; *Balassa*, 1991. 83-87). The maintenance works, however, were mainly done by less skilled workers whom were either paid or they did it as an obligatory work (*Hőgye*, 1986. 188, 195, 216; *Boros*, 1996. 108-109). In the 17th-18th centuries the 'preparation' works, carried out before and continued during vine cultivation, were important and necessary parts of the effective utilization of the area for wine production. These works included, for example, the building of stone terraces, the 'de-stonification' of the (future) area of vine cultivation, preparation and cleaning of ditches, carriage of earth and dung as well as the creation of land-boundaries on steep southern slopes (*Balassa*, 1991. 76-94). The latest in the 17th century, cleaning of ditches (applied especially against the mass erosion work of downpours and cloud bursts) and repairing hedges and terraces in the areas under intensive vine cultivation were systematically controlled by the local official bodies through laws in the Tokaj-Hegyalja wine region (*Balassa*, 1991. 76-78). Balassa in his work clearly connects the above-mentioned anthropogenic features to the traditional ways of soil protection. Similar type of anthropogenic features (stone hedges, terraces, ditches) of the Balaton Uplands (Central Transdanubia), the Mátra Hills, the environs of Eger (both in North-Hungary) and the hills around Budapest as well as the areas of Szekszárd or Pécs and the Villány Hills (all in South-Hungary), formerly connected to vine cultivation now mainly stay abandonned, are in many cases still visible in forests or in areas under the process of reforestation (see e.g. *Baráth*, 1963; *Ádám*, 1975; *Bodnár*, 1987; *Nyizsalovszki*, 2001; *Szilassi*, 2003. etc.).

In the area of Nagymaros, abandonned stone and earth terraces of former vine and cereal production can be found in some of the mainly reforested hilly slopes of southern exposure, the latter observed by *Nováki* (1975. 76). The appearance of short terraces as well as other features such as stone hedges or (stone-bedded) ditches were strongly, nevertheless, dependent on former land use: presumably, in this area they were mainly connected to intensive vine cultivation.

FORMER LAND USE OF THE STUDY AREA

The strongly transformed southern slopes of the former '*promontoria*' in Nagymaros were subject to severe erosion during a longer time of intensive cultivation. These relatively steep (18-22° or even more) slopes of favourable exposure in the Danube Bend, except for the top regions and plateaux, almost everywhere were under cultivation. The main period of (vine) cultivation in Nagymaros can be dated presumably from the 14th to the early 16th and then particularly to the 18-19th centuries (see *Kiss et al.*, 2005). With the application of contemporary maps and images, the land-use changes of the area can be detected in more detail from the second half of the 18th century. Only indirect evidence is available before, referring to the general landscape changes of the areas belonging to Nagymaros (see *Kiss et al.*, 2005).

In the 18th century, most of the manorial vineyards in Nagymaros were located underneath our study area, at the same hill (*Magyar*, 1998. 108, 112). From the earliest maps available from the 18th century, both the estate map (1787-1805; see *Fig. 2*) and the First Military Survey (1784 – HMT, Coll. XII. Sec. 17) suggest that the study area – except for some of the highest, northern parts – was predominantly covered by vineyards at that time. As we could already see, exactly in these decades the Nagymaros wines had a steady market in the Upper-Hungarian mining areas, namely in Selmecbánya (today Banská

Štiavnica in Slovakia; *Magyar*, 1998. 145; see also *Kiss et al.*, 2005). The same was the case in 1856 when, according to the cadaster map and conscription, the study area was part of the vineyard-zone of Nagymaros (OSZK-TK, Bv 1455/1/1-2).

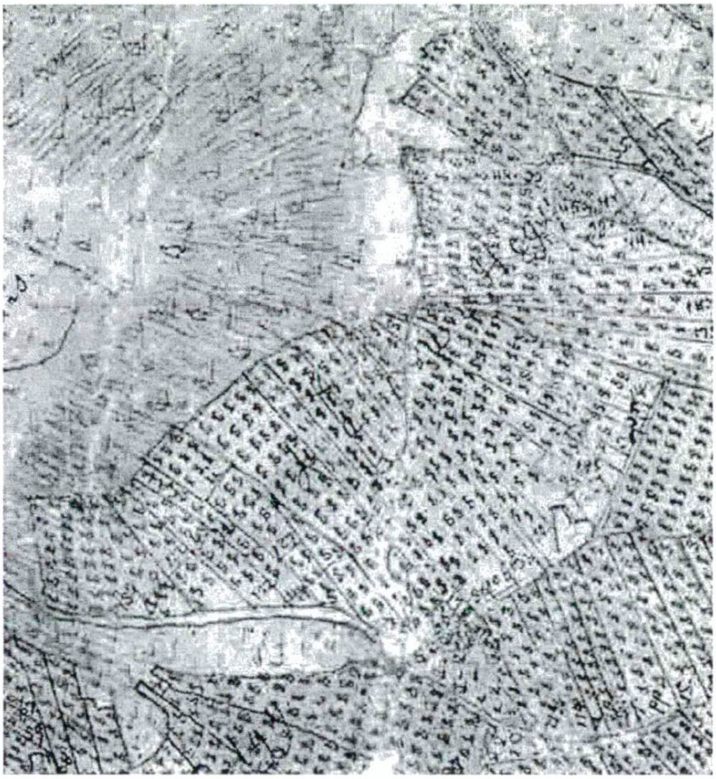

Fig. 2 The study area on the detailed map of the Visegrád-estate, dated to 1787-1805 – MOL, S11. 207/b (original: *ca.* M 1:5760)

On the maps of the Third Military Survey (1872-73 – HMT 4862/3), the sample area is still mainly covered by vinestocks and trees scatttered around; trees seem to be predominant especially in the higher parts of the study area. In the mid-19th century, the Lator-valley, located in the direct neighbourhood of the study area, was mentioned: here around that time vine cultivation was predominant (*Pesty*, 1986. 227). According to the land-consolidation map of 1885-1887, the study area still belonged to the category of 'Vineyards under the town' (MOL, S 11. 832/a). By 1923, on othe other hand, the study area was mainly covered by meadows, trees scattered and partly vineyards and some orchard in the lower sections (1923 – HMT 4862/3).

Approximately similar is the case in the early 1950s when maps still show some cultivated lands of vineyards and orchards in the lower, smaller sections while the more extensive, upper sections are characterised by lines of trees and meadows. The aerial photos taken in 1951, 1962, 1970 and 1987, as well as the new Military Surveys of the 1950s, 1970s and 1980s (HMT – L-34-002-D-b), show a gradual increase of uncultivated lands in the study area. In this sense, the aerial photo of 1951 has special importance: past land boundary structures can be detected probably the most in this case (see *Fig. 3*).

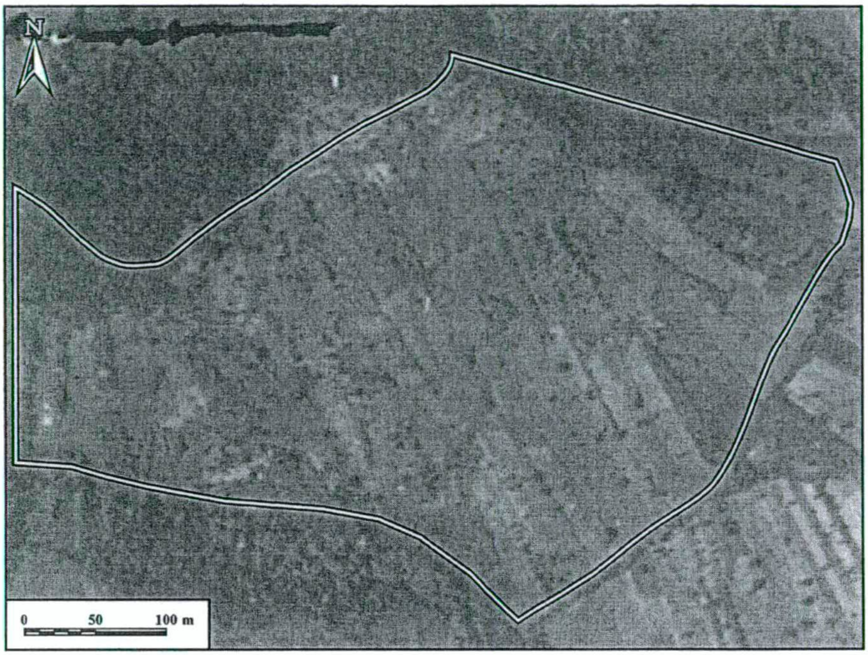

Fig. 3 The study area on the aerial photo taken in 1951 – HMT, L-34-2-D-b (original: *ca.* M 1:20,000)

Another information for the appearance of the today-existing wooden vegetation (thus, when the management of the area ceased to exist) also suggests that the final abandonment of the area did not occur at once but it was the result of a longer process: while the intensive cultivation of the higher and the northern areas decreased first, some of the lowest parts were under cultivation probably even in the 1960s (see e.g. the aerial photo of 1962 – HMT, L-34-2-D-b). According to the dendrochronological survey, based on samples mainly taken from older trees of the species *Quercus petraea L.*, the average age of oak trees was around 44 years (oldest on a terrace: 58). After the age and location of the oldest trees (beyond 50 years each) we can presume that in the upper section of our study area the appearance of 'natural' wooded vegetation in larger number probably started already around the end of the 1940s, beginning of the 1950s.

A '*terminus ante quem*' date can also be provided with the help of approximately a dozen broken roof tiles found at small cube-like places (rectangular 'holes' in stone hedges – probable storage places) both in the middle and the northeastern (lower further) end of the sample area. Their description '*BERGMANN MIHÁLY NAGY-MAROS*' suggests that it was made in the local brick-factory, worked between 1882 and 1945 (*Fischer*, 2005. 8). These roof tiles were presumably produced in a later phase of the factory, thus in the first half of the 20th century, but definitely before 1945 when the factory was finaly closed down.

POSSIBLE CONNECTIONS BETWEEN PRESENT SURFACE CONDITIONS AND PAST LAND USE

Both on the slope and in plateau position – in more or less original morphological situation – the maximum soil-depth is 40 cm, but generally this depth is not more than 25-

30 cm. During the Ice Ages the most important geomorphic proccess might have been the weathering caused by frost, gelisolifluction and debris-creep, which traces can be found at the study area even today in the form of earth-terrace-like features. Thus, based on the form itself, in some cases it is not possible to state clearly whether the actual feature is natural or a heavily eroded former man-made terrace. Due to this problem, only the clearly man-made terraces were measured and included in this article. Near the bare stones lying at the surface of the upper section crioplanation debris, and on this debris the traces of fossil landslides can be detected. Due to the steepness of the slope the solifluction and the slow movement of the andesite debris is active even today, which can be proved by the appearance of several warped trees of the area.

The higher, larger section of the study area can be characterised by meadow vegetation with patches of forested parts, while the lower areas, especially to the south, southwest (where vine cultivation was given up at last) mainly shrubby-scrubby vegetation is predominant. However, the vegetation of the lower areas is quite mixed: the shrubby area is sometimes mixed with forest-steppe at the lower end, while it is almost entirely replaced by young dense woodland towards the northeast. Although the predominant tree species of the area is oak (*Quercus petraea L.*), some other types such as walnut, chestnut, cherry and several other, wild fruit trees are mixed into. While walnut is a typical tree of vineyards, the latter tree of Mediterranean origin presumably came from the chestnut forests nearby, both representative for the area, since until the end of the 19th century some of the main products of the settlement were grapes, wine, chestnut and walnut (see e.g. *Döbrössy*, 2004. 67). The appearance of cherries can also be connected not only to the formerly (early 20th century) significant fruit production of the settlement, but also a possible later land use type of that particular site.

In general, the landscape of the study area shows close parallels to one of the last phases of succession (forest-steppe meadow) typical for former vineyards abandonned several decades before. This level of succession is described by *Baráth* (1963. 346), referring to an area of roughly similar phyisical conditions, located relatively close to Nagymaros (near Budapest). His results were in good agreement with the ones carried out in the abandonned vineyards of the Tokaj-Hegyalja region (e.g. *Nyizsalovszki and Virók*, 2001). However, unlike other former vineyards, the almost entire lack of any trace of vinestocks (we found only two stocks in the lower and the central parts) in our study area is quite striking. One probable reason is that in most parts of the study area vine cultivation could have been given up a hundred, hundred and twenty years ago or even earlier. On the other hand, it is also probable that after vine cultivation was given up in some parts of the study area, remaining vinestocks were at least partly removed since other utilization types (pasture, fruit production) appeared. Zoltán Baráth also emphasised the significance of latter land use in the areas of former vineyards, in connection with the possible directions of vegetation-development (*Baráth*, 1963. 342).

Forestification has most probably started from the oak forest above and around the study area as well as from the older tree lines along the boundaries (see *Fig. 3*) – partly located on stone hedges. In case of the latter ones it is presumable that trees on stone hedges and at boundaries were left even during cultivation on purpose: some ethnographic parallels show that these trees could be regularly cut for, for example, firewood (*Baráth*, 1963. 345). The idea of a conscious 'management' can be supported by the fact that in our study area mainly the old coppice of oak trees can be found on the stone hedges which can be marked as tree-lines on the aerial photo of 1951 (see *Fig. 3*). The other development direction, described by *Baráth* (1963. 344), the abundance of grassy vegetation can be also detected in the study area. The possible deeper connections and further parallels can be discussed only after a more detailed botanical survey of the study area.

TERRACES, STONE HEDGES AND DITCHES

In order to provide a more clear overview, the man-made features of the study area had to be mapped in detail. Due to the steepness of slopes and other problems (very uneven surface, dense vegetation etc.), measurements were carried out by a hand GPS of 5-10 m mean error. For further correction of data, we applied the 'traditional method' of measurements (e.g. compass, tape-measure and angle gauge). Results of measurements are indicated on *Fig. 4*. Additionally, we compared our results to the aerial photo taken in 1951, where due to the still-ongoing cultivation, some main structures of land divisions are still visible (*Fig. 3*).

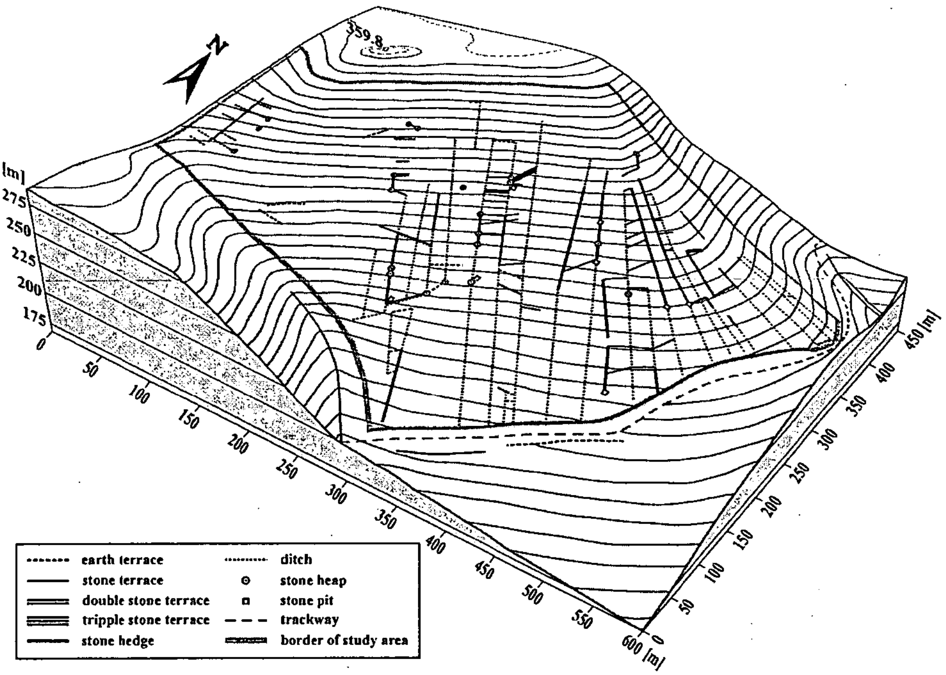

Fig. 4 The 3D model of the study area and the anthropogenic features detected

Located in the study area, the width of anthropogenic, partly stone (*Fig. 5a*) and partly earth (*Fig. 5b*) terraces is rarely more than 10-15 m, while their height changes between 3 and 0.5 m. Some of the terraces (also counted here as stone terrace) show a transitional form: only the two edges, usually along ditches are strengthened by stones. At first site, the location of terraces is not systematic, although they are clearly connected to a former parcel-system: smaller units attached to stone-hedges and/or stone-bedded ditches more in one-one line or alone can be recognised (*Fig. 4*). Terraces of better condition can be found mainly in the central and lower parts of the study area where vine cultivation was given up only in the last phase of abandonment.

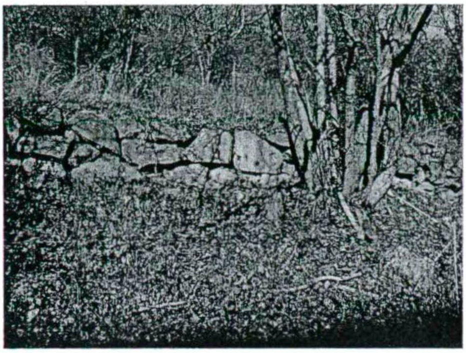

Fig. 5a Stone terrace in the study area

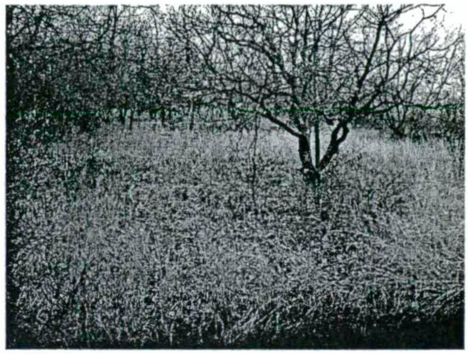

Fig. 5b Earth terrace in the study area

The primary function of both the earth and stone terraces could be to increase protection against soil erosion and probably also to decrease other negative effects such as the steepness of slope; on the other hand, some of the rather massive stone terraces could as well have a boundary function (between the lands of two different owners). Other interesting speciality of many terraces is the inclination of the terrace level towards the ditches and stone hedges. It seems that the original formation of the terrace level had this characteristic feature: namely that the terrace level in this way slowly led the water towards the ditch. Beyond the well-definable terraces, within the boundaries of former parcels, one can find earth terrace-like features in the majority of the study area. Even if these features in many cases show similarities to the former terraced vineyards, described by *Baráth* (1963), due to the above-mentioned natural conditions of the area, we indicated only the terraces of clear anthropogenic origin and in this investigation doubtful cases were left out of *Fig. 4*.

The so-called (both stone-bedded or earth) pseudo-terraces of the area should also be mentioned: these man-made terrace-like features are attached to former paths and small 'tilted' roads (see *Fig. 4*), which – connected to other paths or ditches – in many cases presumably had a draining function as well. Moreover, our study area was surrounded by two (wagon)roads (see *Fig. 2*) where smaller paths led to: while the southwestern one, based on its appearance, really deserves the name of a (stone) pseudo-terrace (only 10-20 cm high), the other – attached to the road closing the study area from the southeast – with its sometimes 2 meter high, long stone walls of several ten meters appear (and is structured) like a real terrace.

In the study area, around 1.5-2 m (maximum 4 m) tall and some ten meters long, stone hedges were detected (*Fig. 6a*); however, not all the stone hedges are accompanied by terraces. Additionally, some smaller and larger stone-heaps (1.5 to 4 m height) were found. According to the distribution of stone hedges, we can divide the study area into two parts: the first, considerably smaller one with two hedges and large stone-piles or heaps is located in the most upperly northwestern part, while the other, larger one with the rest of the stone hedges and most of the terraces can be found considerably lower to the south-southeast (see *Fig. 4*).

Detected either as a separate feature or as a continuation as well as a parallel line of some stone hedges, man-made – both earth and stone-bedded – ditches can be found, mainly along the former boundary lines of separate parcels. The present traces of ditches in some cases are characterised by almost straight lines of trees, possible to be traced back to 10-15 m or even longer (*Fig. 4* and *6b*). The origin of stone hedges, traditionally called as '*obola*,' is presumably strongly connected to the intensive cultivation of a stony area. The stone debris coming out of the ground (before or) during cultivation was presumably thrown to the edges of the parcel (e.g. *Hoffmann*, 1956; *Baráth*, 1963; etc.). The large size of some stone hedges suggests an older origin, and thus there is a possibility that stone hedges of the study area were started forming already in the time of the estate map, namely in the late 18th century or before. Although the stone of the hedges came mainly from the cultivated ground, they must have had a function to confine the boundaries. Ditches presumably led the water of intensive precipitation events from the steep slope and the terraces in order to avoid, or to decrease mass erosion and the development of gullies. While most of the ditches are perpendicular to the slopes, some of them – in many cases connected to pseudo-terraces (see above) – are still today altering the water towards the already-existing gullies or the small valley nearby. Moreover, the size of particular (stone-bedded) ditches might suggest that beyond the above-mentioned function, some of them could have been used as walking paths as well. On the other hand, based on the size and formation of some of the ditches we can presume that not all of the ditches were made to be used as paths: many of them had the single function of leading the water down from the land.

Fig. 6a Stone hedge in the study area

Fig. 6b A former ditch with trees

After mapping the study area, we received a quite complicated picture as a result: many of the traces mapped are well-connectable to the former parcel-boundaries visible on the aerial photo of 1951, some of the main structures, especially the rough framework of the area is also compareable to the estate map of 1787-1809 and the cadaster map of 1886 (see *Figs. 2-4*). It has to be highlighted, however, that our map of man-made features is restricted to those still clearly visible in the landscape; these features are on the other hand only the fragments of a past structures which more or less unevenly remained from the levels of originally well-structured landscape, in continous transition.

CHANGED SOIL STRUCTURE AND ANTHROPOGENIC TERRACES

The former '*promontoria*' zone of Nagymaros and thus, the study area itself belongs to the strongly eroded areas where more than 70% of the original surface layer is eroded (MNA, 80). The average soil depth in the study area is not more than 40 cm: around 40 cm the borer clashed into an impermeable andesite-debris. The physical characteristics of this 30-40 cm upper soil-layer is clay with 10-20 % stone content. It was possible only in some cases to determine genetic layers. This means that there is practically no intact, natural soil profile in the study area, but only resected brown forest soil with clay illuviation where redeposited B-layers appear in the profiles. Consequently, the research carried out at Nagybörzsöny, only some kilometers north to Nagymaros, provides good parallels to our investigations: in the study area of Gyula Nováki, the depth of soil cover reached 40-45 cm only in the strips of the former plough zone, but in the other parts of the area, he counted with only a thin (20-30 cm), redeposited soil (*Nováki*, 1975. 56-58).

The morphology of stone and earth terraces, remained in definable condition, is rather uniform: generally we can find relatively horizontal surface only in a 50-100 cm-wide strip above the upper margin of the terrace (hereafter terrace level). Over the terrace level, after a short, concave transition, the presumably original surfaces can be found down to the bottom of the next terrace (in case there is another one above) with approximately the same angle as that of the natural slope (*Fig. 7*). Since 40 cm or even a bit deeper profiles appeared only at the terrace level and the slope transition, it seems to be proved that terraces were not wider even at the time of their formation, and thus, the narrowness of the terraces is not caused by later earth infilling from the upper sections. Terraces with more than 1 m width are very rarely appear, and they predominantly occur at the stone wall or closing stone terrace located at the lower end of the study area, near the road. Here the average soil depth was sometimes 1.5 m.

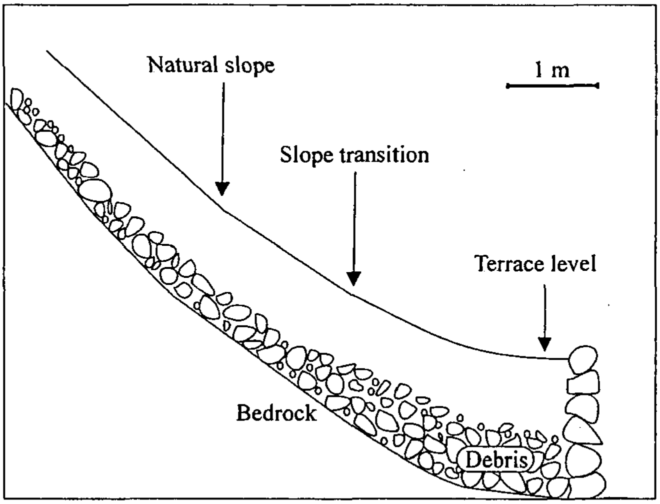

Fig. 7 A simplified structure of terrace-profiles in the study area

The soil depth of terrace levels is altering between 40 and 100 cm, while this depth gradually decreases to 25-40 cm at the slope transition (*Fig. 7*). This structure shows certain similarities to the results of soil sampling (yet unpublished), carried out at some abandonned man-made terraces at Balatonszepezd (Balaton Uplands) in 2002 and 2003: terraces were rather narrow and soil depth was approximately the same (both on slopes and terraces) as that of the ones in Nagymaros. The around 40 cm soil depth can be significant from a cultivation point of view: in case of the traditional vine cultivation techniques the 'active' soil depth of cultivation primarily affected the most upperly 40 cm of the soil (e.g. *Gál*, 2004. 125-128).

Soils of the study area, depending on their genetic layers, can be divided into two groups:

1. In profiles with an average depth of 40-60 cm, genetic layers very rarely can be distinguished, from the surface to the decayed debris homogenous brown forest soil with clay illuviation B-layer were detected. Based on the almost-horizontal morphological situation, significant erosion cannot be detected, and thus, the examined homogenous profiles provided us with the proof that the terrace surfaces received a rather homogenous soil cover (namely, artificial infilling). The basis of the shalllow fertile soil layer is not identical with the top of the original decayed C-layer, but shows that behind the artificially-created stone walls (of the stone terraces) the embankment was carried out applying stone debris and only the upper few 10 cm were filled up with a fertile soil layer (*Fig. 7*).

2. The 60-100 cm deep fertile layers are generally well-distinguished into A- and B-layers. Between the two layers difference can be detected only in the percentage of humus content. Since these all were found on the terraces (terrace levels), we had to give up the theory that the this profile shows an undisturbedly developed genetic soil type; the development of the layers is presumably the result of a deeper or an older embankment. The thicker infilling leads to a much more balanced water and heat economy, which results faster humus development, and thus, a naturally-looking soil profile can develope already within a few hundreds of years. Should we face with terrace-sequences of a much older generation, this can even more generate the possibility of the development of clear genetic soil layers.

The advanced development of soil profile, namely the appearance and clear division of A and B layers of terrace-soils – similar to the large size of stone hedges as well as the structural parallel sin the location of the parcells – mentioned above suggest an older embankment, which mainly could happen a few centuries ago. In addition, this could be an explanation for two other unusual facts that the width of stone terraces rarely exceeds more than 1 m while their soil depth does not significantly differ from the surrounding slope with no terraces. Thus, the lower section of the terrace was filled up with stone debris and then beyond this debris layer the terrace was infilled with a thin soil layer. In this case, therefore, the primary function of terraces was on one hand not only to increase soil depth but rather to preserve the stability of the slope against soil erosion and the formation of gullies. The other function, however, might be connected to vine cultivation: in the 19th century, an adviced method of garden vine cultivation on clay soils was to fill the future vineyard with stone debris or sand and then cover it with some fertilized mixture of the original clay soil where vinestock was planted afterwards (see e.g. *Parragh*, 1860. 79).

CONCLUSION

In the late 18th century, vine cultivation was predominant in the study area. After severe decrease of vine cultivation by the early 20th century, other, less intensive land-use types were invented in the majority of the study area; vine cultivation remained important only in the lower sections. Final abandonment of the area mainly occurred from the early 1950s. Nevertheless, it did not happen at once, but rather gradually, and mainly ended up by the 1960s.

Presumably, stone hedges, terraces and ditches are partly the traces of former land divisions. Terraces and ditches – among other functions – took an active, essential part of protection against severe soil erosion. Although no direct data refers to the age of anthropogenic features in the study area, it seems rather likely that from the beginnings of the (latest) intensive vine cultivation period of the study area, namely from at least the late 18th century, protection and thus certain preparatory works against rapid and irreversible soil erosion were needed. The mapped system of hedges and ditches is presumably a fragment of an old system of boundary lines, since the lines of these objects are in good agreement with the boundary lines marked by trees, still visible in the early 1950s. This structure, however, in its main characteristics can be traced back to the boundary lines depicted on the late 18th-century detailed map of the study area. Moreover, the development of the physical soil structure suggests an early origin of terraces, which structures were mainly connected to the traces of structures characterised by stone hedges and ditches. Thus, the age of terraces cannot be separated from that of the hedges and ditches, and in this sense, for the formation of the described structure, we suggest an early (19th or probably even 18th century) origin.

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TEMPORAL CHARACTERISTICS OF AIR POLLUTANT CONCENTRATIONS IN SZEGED, HUNGARY

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Összefoglalás – Városi környezetben a gazdasági tevékenység és a mindennapi élet a légszennyező anyagok ciklikus időbeli menetét eredményezheti különböző időskálákon. Jelen tanulmány ehhez a megfigyeléshez kíván hozzájárulni a nitrogén-monoxid (NO), a nitrogén-dioxid (NO_2), az ózon (O_3) és az összes lebegő részecske (TSP = total suspended particulate) koncentrációjának a tanulmányozásával egy közepes méretű közép-európai város, Szeged példáján. A vizsgálathoz az említett légszennyező anyagok 1997-2001 közötti ötéves óránkénti koncentráció adatai állnak rendelkezésre Szeged belvárosának egy főútvonal melletti forgalmas közlekedési csomópontjából. Ezenkívül bemutatjuk a heti ciklusoknak a koncentrációk napi menetére gyakorolt hatását, mely különösen fontos, ha e közlekedési eredetű légszennyező anyagok lehetséges szélsőértékeit keressük. Mivel a légszennyező anyagok évi ciklusa a teljes varianciának csupán egy töredékét magyarázza, továbbá a heti ciklus meglehetősen hasonlóan viselkedik a különböző évszakokban, a dolgozatban a napi percentilis értékek heti változását elemezzük az egész évre.

Summary – Economic activities and everyday life may create weekly cycles in concentrations of air pollutants in an urban setting. The present study contributes to this experience on the example of a typical medium-sized town in Central Europe, Szeged, considering the following air pollutants: NO, NO_2, O_3, O_x and TSP. Five-year data sets of hourly observations (1997-2001) collected near a highway, in a downtown traffic junction are analysed. In addition, the modulating effect of the weekly cycle on the diurnal course of the air pollutants is also demonstrated, which is especially important when we consider the possible extremes of these traffic related air pollutants. Since the annual cycle of the pollutants explains only a minor part of the total variance and, furthermore, the weekly cycle behaves rather similarly in the different seasons, the weekly modulation of the diurnal peaks is quantified for the whole year.

Keywords: urban air pollutants; nitric oxide, nitrogen dioxide, ozone, total suspended particulate, weekly cycle, diurnal cycle

INTRODUCTION

Air pollution is one of the most important environmental problems, which is restricted mostly to the cities. Generally, human activities induce monotonous accumulation of pollutants. Population growth in cities and, in connection to this, the increase of built-up areas is considered to be some of the underlying reasons for worsening air quality. A considerable part of population growth derives from migration to the cities. The ever-increasing urban population, together with the growing industrialisation and energy consumption, and the extensive transportation, increase air pollution which becomes a more and more serious challenge for the interest of survival. The main sources of air pollution are industrial activity, motor vehicle traffic (which heavily affects air quality in densely urbanised regions) and emissions from building heating systems (contribution of which is important in the winter period). Air pollution is harmful to the buildings, technical devices and may cause serious health damage, as well. The nature and importance of air quality problems depend on the size of the city, as well as various physical and chemical processes (industrial activity), meteorological processes (climate, local meteorological conditions at the moment), geographical processes (structure and quality of the surface, vegetation cover, position, relief) and social factors (existing environmental regulations, urban planning policies) (*Mayer,* 1999).

Air pollutants can be divided into two groups: The traditional Major Air Pollutants (MAPs), include sulphur dioxide, nitrogen dioxide, carbon monoxide, particles, lead and the secondary pollutant ozone). The Hazardous Air Pollutants (HAPs), include chemical agents [e.g. volatile organic compounds (VOC), benzene, polyaromatic hydrocarbons (PAH)], physical agents (e.g. depositing dust coming from the surface, yellow dust in China forming loess) and biological agents (e.g. pollen of plants). The HAPs are generally present in the atmosphere in much smaller concentration than the MAPs and they often appear more localised, but they are – due to their high specific activity – nevertheless toxic or hazardous. Both in scientific investigations and in abatement strategies HAPs are difficult to manage not only because of their low concentrations, but also because they are in many cases not identified (*Fenger,* 1999).

Research on urban air has a wide literature. Some of these are concerned with the analysis of characteristics of pollutants (e.g. *Olcese and Toselli,* 2002), others deal with the spatial and temporal variability of those (e.g. *Hunová et al.,* 2004), or investigate statistical interrelationships among the variability of pollutants (e.g. *Qin et al.,* 2004), or examine social policy on regulating emissions (e. g. *Fehrenbach et al.,* 2001), or study the connection of meteorological parameters with major/hazardous air pollutants (e.g. *Raga et al.,* 2001; *Makra et al.,* 2004), or evaluate urban air quality using special models (e.g. *Jorquera,* 2002a, 2002b) and special air quality indicators (e.g. *Mayer et al.,* 2004).

Motor vehicle traffic seems to be one of the most important sources of air pollution, mainly in the cities. Cities in Hungary, especially the big ones like Szeged, together with the population, and the number of motor vehicles, are continuously expanding. Consequently, a more significant role should be assigned for traffic as potential air quality influencing factor in the future (*MEH,* 1999).

In Hungary, motor vehicle traffic related emissions of CO, NO_x and TSP (total suspended particulate) are around 70 %, 55 % and 14 %, respectively, of the total emissions of these pollutants (*MEH,* 1999).

The traffic system of Szeged is considered to be overcrowded. Among vehicles, taking part in the traffic, the ratio of passenger cars is the highest (84 %). During the 11-year period between 1990-2000, traffic density has not changed considerably. However, the types of vehicles have been fundamentally modified. Emission from more and more vehicle types decreases significantly, as the ratio of vehicles equipped with catalytic converter keeps increasing. Hence, in contrast to stagnant traffic density, emissions of vehicle related air pollutants have been decreasing considerably. This way, e.g. CO emissions of motor vehicles in the year 2000 were only 35-40 % of those measured in 1990 (*Pitrik,* 2000).

The major aim of the present study is to determine the temporal characteristics (typical diurnal, weekly and annual course), as well as statistical interrelationships of air pollutants; furthermore, to analyse their interrelation with meteorological elements.

DATA AND METHODS

Location, structure and climate of the town

Szeged ($\varphi = 20^0 06'$E; $\lambda = 46^0 15'$N; h = 79 m a.s.l.) lies near the confluence of the Tisza and Maros Rivers. It is one of the largest cities in Hungary with 155,000 inhabitants covering an area of about 46 km^2 (*Fig. 1*). Szeged and its surroundings occupy a flat and open region and the city has the lowest elevation value in whole Hungary.

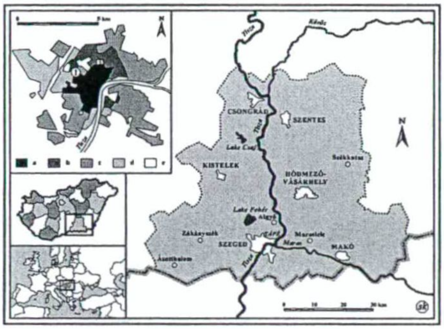

Fig. 1 Geographical position of Szeged, Hungary and built-up types of the city [a: centre (2-4-storey buildings); b: housing estates with prefabricated concrete slabs (5-10-storey buildings); c: detached houses (1-2-storey buildings); d: industrial areas; e: green areas; (1): monitoring station]

The total urban spread extends well beyond the city limits and includes the largest oil field in Hungary with several oil torches, just north of the town. This oil field is a significant source of NO_x and sulphur dioxide. The power station, located in the NW part of the town, and motor vehicle emissions have largely contributed to the nitrogen oxide levels at Szeged.

The mean annual temperature is 11.2 °C, while the mean January and July temperatures are -1.2 °C and 22.4 °C, respectively. As for yearly averages, the annual precipitation is 573 mm, the relative humidity is 71 %, wind speed is 3.2 m s^{-1}, and sunshine duration is 2102 hours.

The basis of the city structure is a boulevard-avenue street system cut trough by the Tisza River. This way, though the structure of the city is simple; however, due to this system, motor vehicle traffic as well as air pollution is concentrated to the downtown areas. The industrial area is located mainly in the north-western part of the town. Thus, the prevailing westerlies and northerlies transport pollutants, originating from this area, towards the centre of the city as well.

Measurement of the pollutants considered

The database consists of thirty-minute averages of the air pollutants examined. Average daily mass concentrations of NO, NO_2, O_3 and TSP (µg m^{-3}) are used for the five-year period between 1997-2001. The data comes from the monitoring station in Szeged downtown, located at a traffic junction (in the intersection of Kossuth Lajos blvd. and Damjanich street – Teréz street) (*Fig. 1*).

Calibration of gas analysers occurs at two points. One of them is the 0-point, which is set automatically in every 24 hours, while the other calibration point is set once in every fortnight by a verified sample. Calibration of the O_3 instrument is performed via gas phase titration. The verification of TSP measurements occurs once in every quarter of a year.

A personal computer serves to perform instrumental control and data storage. Data are produced primarily as one-minute averages from ten-second measurements. Then, thirty-minute averages are determined and stored.

RESULTS

Annual cycle of the pollutant concentrations and its effect on variability

The diurnal concentrations of NO display a clear annual cycle, while those of NO_2 and TSP indicate less definite ones with much higher fluctuation around this cycle. However, annual cycles for all three of them are characterised by winter maxima and summer minima. In contrast, the diurnal concentrations of O_3 with a clear annual cycle have a winter minimum and a summer maximum (*Fig. 2*).

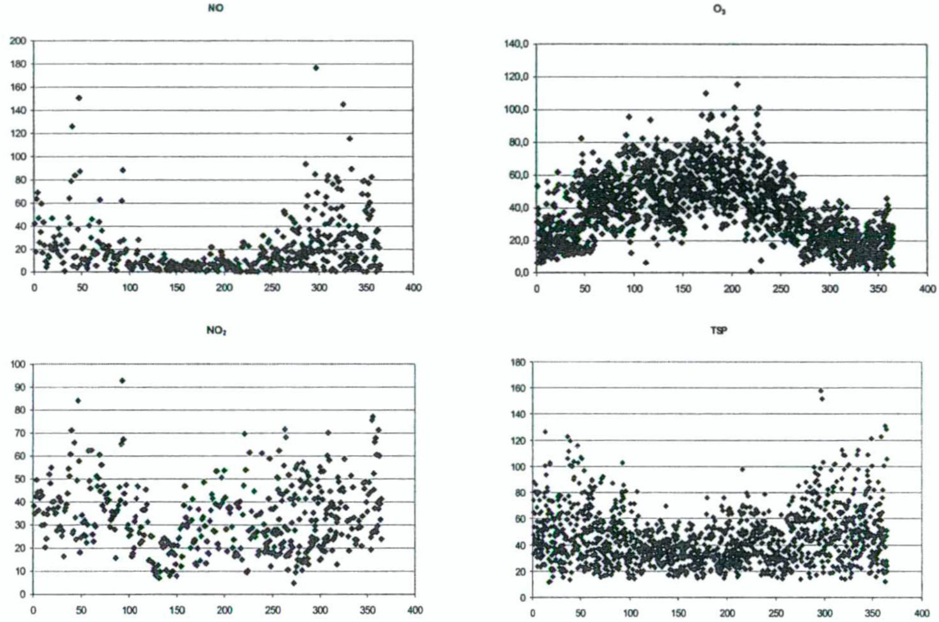

Fig. 2 Diurnal concentrations of NO, NO_2, O_3 and TSP ($\mu g\ m^{-3}$), 1997-2001

The average weekly cycles of the air pollutants, after the annual cycle had been removed, were also determined. For this, three seasons were defined: Winter (WI) (November-February); Summer (SU) (May-August) and a Transient Period (TR) (March-April and September-October). The average weekly cycles of NO, NO_2 and TSP are very similar with weekday maxima and weekend minima. The highest concentrations are observed in the winter, while the lowest ones in summer. On the other hand, that of O_3 has weekday minima and weekend maxima. On weekdays the concentration of traffic related NO is high. After reacting with O_3, its concentration is decreased:

$$NO + O_3 \longrightarrow NO_2 + O_2 \qquad (1)$$

Conversely, at the weekend, the concentration of O_3 is high, due to the relatively low traffic (*Fig. 3*).

Fig. 4a depicts the average annual cycles of NO, NO_2, O_3 and O_x, where O_x is a measure of the O_3 concentration, contained in an air mass. It is defined as the sum of NO_2 and O_3 and is more suitable for the assessment of the photochemical O_3 budget than O_3

alone, because it takes the reversible chemical processes into account as well (*Mayer*, 1999).

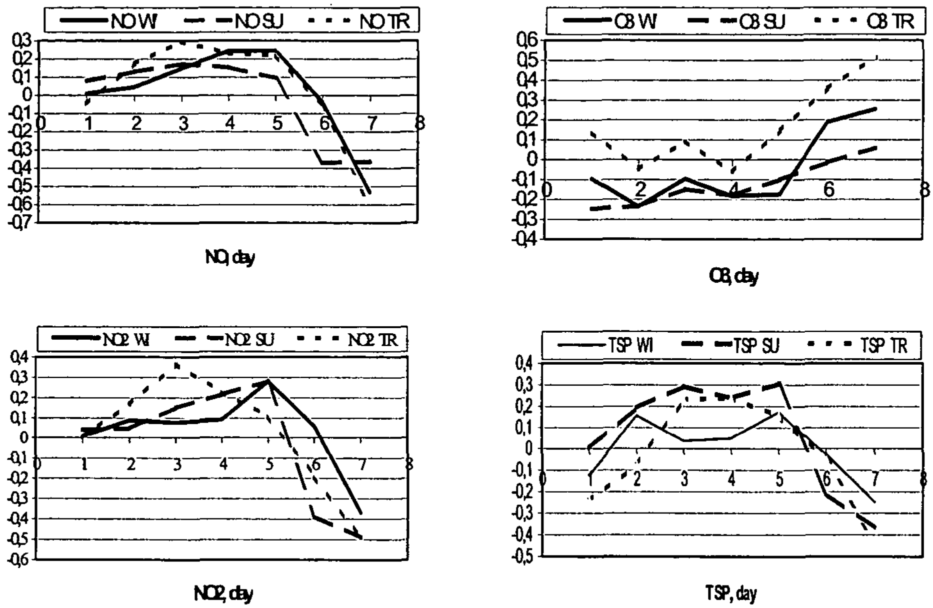

Fig. 3 Average weekly cycles of NO, NO_2, O_3 and TSP in the three "seasons" ($\mu g\ m^{-3}$), (1 = Monday, ... , 7 = Sunday), 1997-2001

The annual cycle of the primary air pollutant NO displays the greatest values in November, December and January, with a maximum in February (*Fig. 4a*). As the NO concentration depends not only on the rate of emission, but on the prevailing weather conditions as well, higher winter values refer to atmospheric stability with frequent inversions. The average annual cycle of NO has the lowest values during the summer (June and July), when air mass exchange is the most intensive. The annual cycle of NO_2, a secondary substance produced mainly by chemical reactions, follows a similar course to that of NO. Tropospheric ozone is produced via the effect of short-wave radiation on substances emitted from anthropogenic sources. The role of solar radiation in the troposphere, producing photochemical O_3 can be expressed by the following pair of chemical equations:

$$\begin{aligned} NO_2 + h\nu &\longrightarrow NO + O \\ O + O_2 + M &\longrightarrow O_3 + M \end{aligned} \qquad (2)$$

(*h*: Planck-constant; *ν*: frequency of irradiance; *M*: usually a molecule of O_2 or N_2) (*Sindosi et al.*, 2003). Consequently, the average annual cycle of O_3, together with that of O_x, has the greatest values in the summer (June and July) (*Makra et al.*, 2001). The annual cycles of these pollutants are very similar to those observed in Stuttgart, Germany (*Mayer*, 1999). The average annual cycle of the total suspended particles has the greatest values in November, December and January, with a maximum in January (*Fig. 4b*). Higher winter values might refer to atmospheric stability with frequent inversions. The lowest values during the summer (June, July, August and September) can be explained by dilution caused by an intensive vertical exchange in the atmosphere.

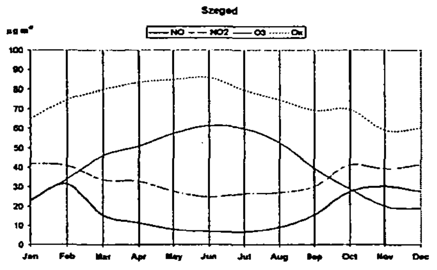

Fig. 4a Average annual cycles of NO, NO_2, O_3 and O_x, monitoring station, Szeged, 1997-2001

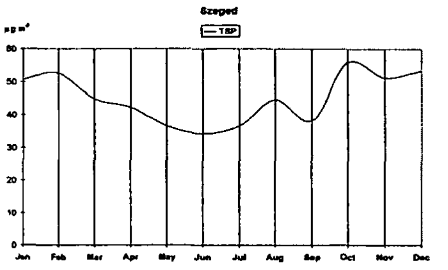

Fig. 4b Average annual cycle of TSP, monitoring station, Szeged, 1997-2001

The weekly and diurnal cycles of the pollutant concentrations

The diurnal cycles of NO and NO_2 (*Fig. 5a*) have the shape of a double wave, with bigger amplitudes for NO than for NO_2. Due to the traffic density, the concentration of NO is relatively higher on weekdays, than on weekends. This effect can also be observed for the secondary substance NO_2. The average diurnal variations on weekdays are greater for NO than for NO_2, because NO_2 has a longer lifespan than the more reactive NO. Generally, the NO concentrations are higher in the morning, then in the evening. This can be explained by the fact that in the morning the rush hour is shorter, and the atmosphere near the surface is more stable than in the evening. The low NO concentrations early in the afternoon result mainly from the reduction of O_3 by NO. The diurnal cycles of O_3 show a clear daily course with one wave. A maximum takes place in the early afternoon caused by photochemical O_3 formation, while a minimum occurs after midnight. On the basis of its definition, the diurnal cycle of O_x is similar to that of O_3. On weekends, the average O_3 maximum values are a little higher than on weekdays, but this is not valid for O_x (*Makra et al.,* 2001).

In comparison with the air pollutant characteristics in Stuttgart, the average weekly and diurnal cycles of the pollutants at Szeged are on the one hand less extreme with only a few large fluctuations. On the other hand, the values themselves are lower. Furthermore, slight secondary extremes in the cycles cannot be presented (*Mayer,* 1999). The above mentioned characteristics at Szeged may be attributed to a lower traffic density. However, the lack of secondary extremes might be caused by the short time courses of the pollutants.

The weekly and diurnal cycles of the total suspended particulate (TSP) (*Fig. 5b*) have the shapes of double waves. Both primary and secondary maxima can be observed during peak hours and, in the same way, primary and secondary minima occur, when traffic is the lowest (at night) or is decreasing (around midday). Also, due to the dense traffic, the concentration of TSP is relatively higher on weekdays.

Analysing NO and NO_2 peak values, it becomes obvious that the highest values occur most frequently in the evening (*Figs. 6a and 6b*), while the diurnal cycle of mean NO concentrations has its local maximum in the morning (*Fig. 6a*). O_3 peak values show a maximum during the weekends (*Fig. 6c*). Within this, in agreement with the occurrence of the average O_3 maximum values mentioned above, they have a definite maximum on

Sunday. If we compare the *Figs. 6a-c* for Stuttgart with those for Szeged, we can see that the Stuttgart curves have higher concentration values, larger fluctuations and clearer cycles of secondary extremes than those for Szeged (*Makra et al.*, 2001; *Mayer,* 1999).

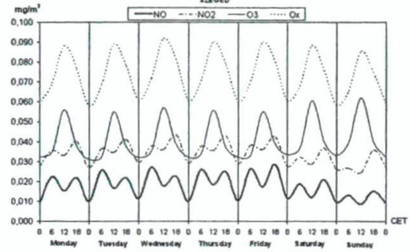

Fig. 5a Average weekly and diurnal cycles of NO, NO_2, O_3 and O_x, monitoring station, Szeged, 1997-2001

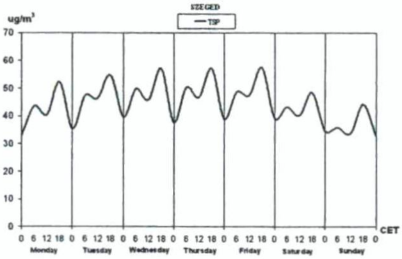

Fig. 5b Average weekly and diurnal cycle of TSP, monitoring station, Szeged, 1997-2001

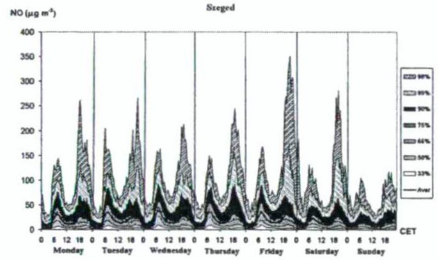

Fig. 6a Average weekly and diurnal cycle of percentile values of NO, monitoring station, Szeged, 1997-2001

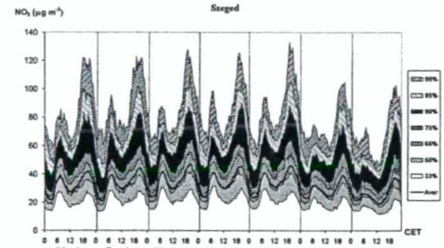

Fig. 6b Average weekly and diurnal cycle of percentile values of NO_2, monitoring station, Szeged, 1997-2001

Peak values for TSP show a double wave displaying maxima late in the evening, while secondary maxima can be observed late in the morning. The lowest TSP concentrations are measured early in the morning, while secondary minima occur in the evening (*Fig. 6d*). The average annual, weekly and diurnal cycles, as well as the average weekly and diurnal cycle of the percentile values of TSP are very similar to those of NO, which indicates the relation of TSP to traffic densities.

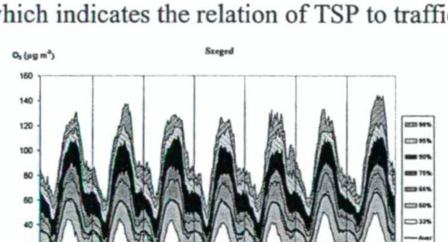

Fig. 6c Average weekly and diurnal cycle of percentile values of O_3, monitoring station, Szeged, 1997-2001

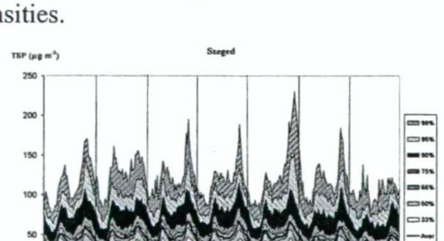

Fig. 6d Average weekly and diurnal cycle of percentile values of TSP, monitoring station, Szeged, 1997-2001

CONCLUSIONS

The new findings of this work can be summed up as follows:

- The air pollutants examined show typical annual weekly and diurnal cycles.
- The average annual cycles of NO, NO_2 and TSP (with maxima in winter) are opposite to those of O_3 and O_x (with maxima in summer). The higher winter values are caused by atmospheric stability with frequent inversions. The lowest values in summer are due to dilution caused by intensive vertical exchange in the atmosphere. The highest intensities of photochemical O_3 formation are observed during the early afternoon and the summer.
- The concentrations of NO, TSP and O_3 are traffic related. Concentrations of NO and TSP (O_3) on weekdays are high (low), while on weekends they are low (high).
- The average weekly and diurnal cycles of NO, NO_2, O_3 and O_x have lower values and less extremes in a middle-sized Central-European city (Szeged), than those observed in a great one (Stuttgart) in a developed country (Germany).

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RESEARCH ON THE HEAVY METAL POLLUTION OF SOME CAVE WATERS OF THE KARSTS OF AGGTELEK FROM 2000 UNTIL NOW

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Összefoglalás – Napjainkban a környezetszennyezések vizsgálata során egyre gyakrabban előtérbe kerül a nehézfém terhelések táji értékelése. Annak ellenére, hogy a nehézfémek környezetünk természetes alkotóelemei közé sorolhatóak, potenciálisan toxikus anyagoknak tekintjük azokat. Afémek biológiailag nem bonthatók le, az élő szervezetbe kerülve ott felhalmozódhatnak. 2000 decemberétől az Aggteleki-karszt területén 7 alkalommal volt lehetőségünk mintavételezésre. A terület fémszennyezettségét nem csak vízminták (forrásvizek, barlangi csepegővizek), hanem több helyről gyűjtött barlangi agyag alapján is vizsgáljuk. A kutatás része annak a vizsgálatnak, amely a karszterületek talajainak és azok növényzetének nehézfémszennyezettség vizsgálatát is célozza. Amennyiben kimutatható a talaj – növényzet – és vízrendszer terhelésének kapcsolata, az a tájkezelés számára a jövőbeni környezetvédelmi problémák egy szegmensének feladatait is megjelölheti.

Summary – Nowadays, the research of environmental pollution come to the front the importance of heavy metals in the landscape classification. However the heavy metals are the natural component of the environment, we have to look them toxic materials. Our goal is to determinate the degree of the impact of heavy metals on the karsts, which are sensitive for the environmental changes. Since 2000, we collected cavewater samples from five different locations of caves and springs and we have also clay samples from the Baradla cave, that was analysed too. Until now the results shows, the content of metallic contents in the cave waters are higher than the expected. The analysis of heavy metal-contamination cave waters is a part of the investigation of heavy metal pollution in karst soils and vegetation. In case, we can to detect the interaction among soil, vegetation and hydrology, that would show to a new way in the managemant of future environmental problems.

Key words: metal pollution, karst water, Aggtelek National Park

INTRODUCTION

Nowadays the evaluation of heavy metal pollution on the landscape level is gaining importance. Although heavy metals are natural components of the environment, we have to consider them potentially toxic materials.

Heavy metal concentration has increased in the air, soil and waters, especially in the cities and industrial areas. According to predictions based on research monitoring changes in the metal concentrations in the soil and plants, heavy metals will probably become important environmental stress factors over the next decades (*Pais,* 1992). One reason for this is that the metals are not biodegradable therefore they get cumulated in living organisms. This makes it absolutely necessary to investigate these toxic metals in the karsts as well.

Karsts are one of the most sensitive areas from the environmental and conservation point of view (*Jakucs,* 1971). The karst is a complex system formed by the interaction of the geological construction, the water, the soil and the vegetation (*Keveiné Bárány,* 1998). The effects of these factors on each other are very diverse; if any of these factors change, the whole system will be modified in a way that is hard to predict. Karsts react very fast to anthropogenic impact because their hydrological system is open and has a 3-dimensional surface.

The motor of the evolution and change of karst areas is water that also plays an important role in providing the drinking water supply. 25% of the world's population gets the drinking water from karst waters, therefore the effects of pollution cannot be neglected in future research (*Keveiné Bárány et al.*, 1999).

In our investigations we try to trace the heavy metal pollution of the Aggtelek Karsts by the analysis of samples collected in the catchment areas of the Baradla-, Béke-, Kossuth- and Vass Imre caves. We have had the possibility to collect samples 7 times since December 2000. Besides investigating the metal pollution on the basis of water samples (spring-waters, caves dropping waters) we also used clay from the caves, collected in different places. Our aim is to answer the following questions:

- Is there significant pollution in the examined waters?
- Is there any similarity between the water qualities of the different sampling points?
- How does the metal concentration change in the studied karstic hydrological systems, is there any self-cleaning or does the strain increase in the karsts?
- Is it possible to conclude the place and the properties of the pollution sources from the results?

It is really important to know these processes because the results can only be seen after a certain time, when it is already impossible to interfere. Still, the reclamation of the bigger karst springs is still in process, they are being joined to the water-supply systems. Some of these satisfy local needs (Babot-well, spring Kis-Tohonya) but the newly claimed springs also help to solve the water supply problems of remote settlements (spring Pasnyag and Papkerti).

During the last decades some similar researches were taken, on an international level, but the karst springs of the Aggtelek region in Hungary have never been examined from this point of view yet. Since spring water is an important basis of the drinking water supply it is extremely important to research today's moderate pollution to be able to take protection measures in the future.

The examination is expensive and requires a lot of data. The elemental composition of the dropping waters can change very fast, even day by day; therefore if we talk about the general trends we cannot base our research with total confidence on random samples and momentary measuring results. We dedicate our data to attract attention to the problem and to serve as a basis for the next researches. For further research we will need further measurements from a longer period, and to start monitoring.

SAMPLING POINTS AND METHODS

The metal content of the water samples was defined by the use of an atomabsorption spectrophotometer in the laboratory of the Department of Physical Geography (University of Szeged).

Due to the geological, tectonical ad morphological diversity of the Aggtelek-Rudabánya karst area, there are 90 smaller ad bigger karst springs that bring the karst waters of the different chalk and dolomite areas to the surface. The rising places of the karst springs are determined by the geological structural lines. Among these, we selected 5 springs situated relatively close to each other. At least one cave belongs to each spring and one of the selection criteria was the accessibility of the caves' interior. We examined the following caves:

- Baradla-cave – Jósva-springs:
  - Rövid-cave spring
  - Hosszú-cave spring
- Béke-cave – Komlós spring
- Kossuth-cave – Nagy-Tohonya spring
- Vass Imre cave – Kis-Tohonya spring
- Rákóczi I. cave
- Földvári cave

We collected water samples in the Baradla cave from at least 3 different places. One of these is Acher in the Orchestra Hall, which is situated in the built up part of the Aggtelek side of the Baradla cave. In rainy weather we collected from the Styx, also at the Orchestra Hall. The Retek branch is at the middle of the cave; its water usually comes from the Zombor-Lyuk sinkhole. The active dropping water of Csipkés-well is situated at the Vörös-lake entrance on the Jósvafő side.

Sometimes, in rainy periods we also took some dropping water samples, usually around the Orchestra Hall. We also collected the clay samples around the Orchestra Hall and from the Kúszó branch of the Retek branch.

DISCUSSION AND RESULTS

Chalks do not generally have a high level of heavy metals concentration. According to *Merian* (1984) chalks contain the following average heavy metal concentrations: Cu: 4, Co: 2, Cd: 0.165, Ni: 15, Pb: 5, Zn: 23, Mn: 700 ppm.

Kabata-Pendias and Pendias (1984) present the data regarding the metals in intervals: Cu: 2-10, Co: 0.1-30, Cd: 0.035, Ni: 7-20, Pb: 3-10 ppm. *Brümer* (1991) created a mobility order based on pH: Cd: pH<6-6.5, Mn, Ni, Zn, Co pH<5.5, Al, Cu pH<4.5, Pb becomes more mobile at pH < 4. From this it is clear, that lower pH usually increases the heavy metals' mobility, and so their getting into the soil suspense.

We have determined the following metals' concentration in the water samples: lead, cadmium, zinc, cobalt, copper, iron, manganese, nickel and chrome.

The results of the 7 rounds of water samples from Aggtelek were quite in harmony with our previous examinations *(Keveiné Bárány et al.,* 1999).

All the samples are polluted with lead; the concentrations are higher than the threshold limit for drinking water. Between 2000 and 2002 we found cadmium pollution in the water, but this pollution has disappeared from the karsts by now.

While in 2000 we found lead to have the highest concentrations in the Hosszú cave of the Jósva spring and in 2004 again in the Hosszú cave and in the Babilon's mount 10.153 mg/lt. In the Nogy-Tohonya spring lead content was higher (in 2000 0.042 m/l, in 2004 0.118 mg/l) than in the siphon lake at the end of the Kossuth cave (2000 0.025 mg/l, in 2004 0.094 mg/l). In the past 5 years the concentration of lead increased in the water samples so we can suppose that lead concentration in the caves is being replenished and so getting higher. The lead and cadmium content of the karsts waters in December 2002 increased significantly compared to the concentrations measured in August 2002 and all are higher than the drinking water threshold limit. The highest level of lead pollution was found in the Retek branch (over 0.39 mg/l), the lowest in the Kis-Tohonya and the Nagy-Tohonya springs.

There's an opposite tendency in the Béke cave during the years 2000-2001. The lead concentration of the water in the cave was higher (0.029 mg/l) than at the Komlós spring where the concentration was exactly at the threshold limit (0.01 mg/l). The reason for this can be the pool dammed up by the sinter. From this pool the occasional pollution gets to the surface slower (this can be proved by a further analysis of the lake's mud). Another reason for this might be that the water got mixed with water from other springs and got attenuated (this will be the object of further investigations). Still, by December 2004 we found just half of the earlier concentrations at the Béke cave (0.0525 mg/l, after measuring samples taken from 2 different places) and the spring's lead concentrations were higher.

The same tendency appears in the case of cadmium concentrations in 2003 and 2004. The zinc, cobalt, copper and nickel concentrations did not exceed the threshold limit for drinking water in 2000 and 2004. In the samples from 2000 the quantity of chrome exceeded the limit only at the Béke cave (0.062 mg/l). However, high chrome concentrations could also be observed in the Komlós spring. In the other springs chrome hardly ever appeared, so it is only typical at the Béke cave catchment area. In 2001 chrome did not appear in any of the springs save Béke cave, however, the concentrations there were also lower than in the previous year and did not exceed the drinking water threshold limit.

In the samples of 2002 the chrome concentrations of all the catchment areas were already high, several times the threshold limit. The highest concentrations were found in the Baradla cave, in August (in the Retek branch, we found a concentration of 1.722 mg/l. In the Csipkés-well, which is active dropping water so chrome could not get concentrated behind a sinter, we measured 1.652 mg/l and the threshold limit is 0.05 mg/l!) The highest concentrations appeared in the Alsó-Hosszú cave of the Baradla cave and in the Rövid cave. The Baradla cave catchment area was obviously affected by serious pollution, followed by that of the Vass Imre and Béke caves. In the Kossuth cave catchment area chrome did not appear in August, only in October. So we suppose that the pollution arrived at the area from the north-west because the highest concentrations were found there.

By October 2002 the chrome concentrations in the Baradla cave were lower than in August; highest were those in the Rövid cave of the Jósva springs. By December the chrome concentrations were reduced; they were still higher than the drinking water threshold limit but much lower than in October. Thus, we supposed that the pollution was gradually leaving the cave. Each of the measured concentration levels exceeded the drinking water threshold limit (*Figs. 1-3*). We measured similar values in the dross samples brought from the Baradla cave.

In December 2004 we only found detectable chrome quantities in the Baradla cave at the Acheron (0.025 mg/l), at the Nagy-Tohonya spring (0.008 mg/l) and at the Komlós spring (0.0064 mg/l) but these were under the threshold limit *(Fig. 4)*. Therefore we can conclude that there was a self-cleaning process in the caves after a major chrome pollution in 2002.

In all the samples of 2002 zinc concentrations exceeded the drinking water threshold limit; they reached the highest values at the Komlós spring but by the end of 2004 they got lower and stayed under the limit. Similarly as in the case of the chrome content we can conclude that the pollution was leaving the territory. We reached this conclusion on the basis of the metal concentrations of the samples from the Baradla cave; in the sample taken in August the metal content was higher at the side nearer to the sinkholes while in October higher concentrations were found at the springs. Meanwhile in August concentrations were higher than in October. We can compare the spreading of the pollution to the passing of a wave. High zinc content is not only characteristic of the Baradla cave catchment area since we also met high concentrations in the Komlós spring; therefore we suspect the concentrations also increased at the Béke cave catchment area.

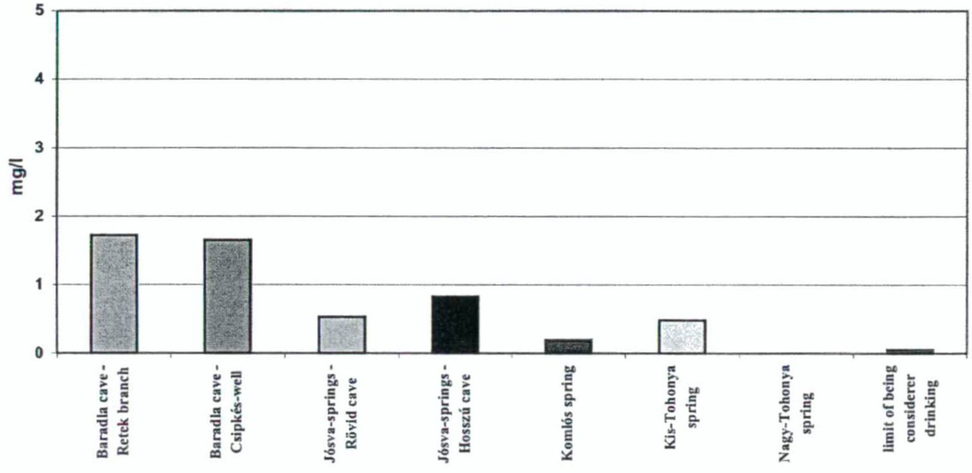

Fig. 1 Chromium content of the Aggtelek karst waters in August 2002

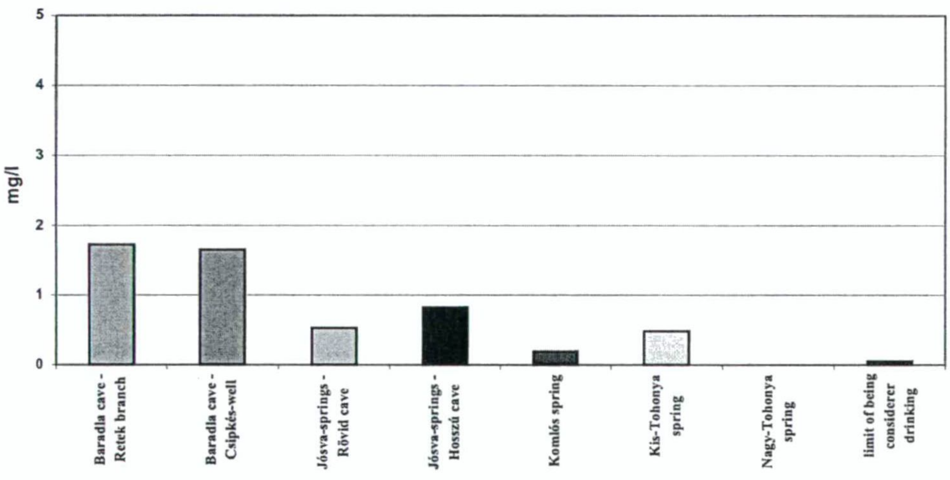

Fig. 2 Chromium content of the Aggtelek karst waters in October 2002

In the samples of August 2002 of the Baradla and Vass Imre cave's catchment areas we found nickel concentrations higher that the threshold limit. In the Retek branch the nickel content reached a value of 0.312 mg/l (the drinking water threshold limit is 0.2 mg/l) and in the Hosszú cave the concentration was 0.288 mg/l. Of the samples taken in October only the Hosszú cave sample (0.43 mg/l) exceeded the drinking water threshold limit. In August 2004 we only found higher nickel concentrations in the Komlós spring and in the Hosszú cave of the Jósva springs (0.321 mg/l and 0.253 mg/l) where the concentrations decreased to a value of 0.1 mg/l by December 2004.

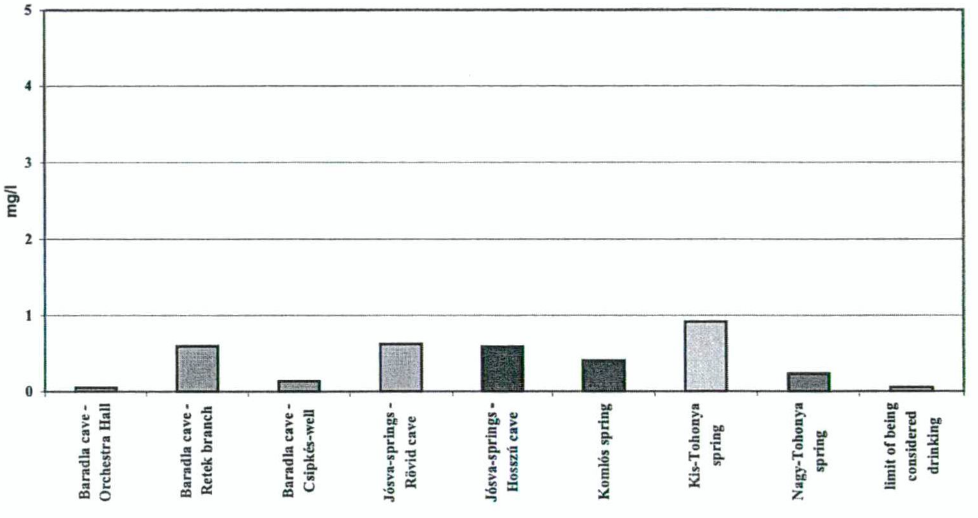

Fig.3 Chromium content of the Aggtelek karst waters in December 2002

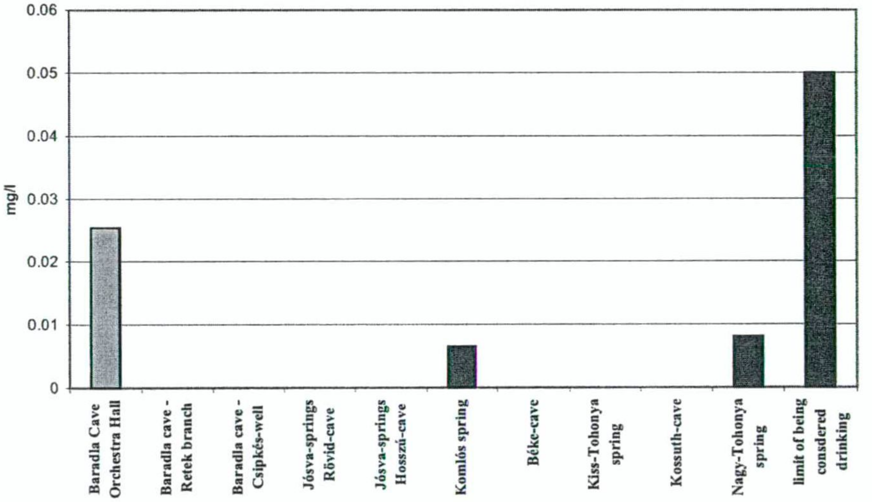

Fig.4 Chromium content of the Aggtelek karst waters in December 2004

In October and December 2002 the manganese content of the Retek branch of the Baradla cave (1.977 mg/l than 12.220 mg/l) significantly exceeded the threshold limit (0.5 mg/l). We did not find high concentrations elsewhere on any other occasion.

In conclusion, we can say that according to our examinations of the samples of 2000, 2001 and December 2002 there was a cadmium pollution in the area, along with a constant lead pollution, while in 2000 a lead pollution occurred and in 2001 higher iron and manganese concentrations appeared. In 2002 a pollution wave swept over the area which means the chrome, nickel and zinc concentrations were especially high. This wave disappeared by 2004 due to a self-cleaning process in the karst.

The metal concentrations of the dross samples have exceeded the threshold limit only once but they were visibly lower in the orchestra hall then at the Kúszó branch junction of the Retek branch. The chrome concentration of the soil is 10 times higher than the threshold limit; this confirms also our conclusion that there has been chrome pollution at the territory.

POSSIBLE ORIGINS OF POLLUTION

Generally pollution can get to the karst interior in three ways *(Csernavölgyi,* 1978) The fastest way is through the sinkholes. Through an open sinkhole the water can get inside the rocks without any barrier. In case a non-karstic catchment area also belongs to the hydrologic system, the pollution originating from there also enters the karst without any barrier. In the case of temporal sinkholes, which are usually more or less filled up, there is a certain degree of filtering.

Infiltration at the rock border usually occurs next to a local erosion basis, especially if the surface landuse has high pollution potential (like intensive agriculture, garbage storage, etc.).

The third way is the infiltration from the surface. This is a slow but constant phenomenon that usually occurs in agricultural areas (due to the use of fertilisers, herbicides and other chemicals) and in settlements (sewage, polluted precipitation). The significance of the three ways and their proportion can be influenced by the surface weather conditions, especially by precipitation (*Parrag,* 1997).

Infiltrating water from precipitation plays the most important role in replenishing the karst water supply. According to the examinations of the VITUKI Research Centre the precipitation here is a bit acidic (pH=4-6) and rather polluted that is caused by the nitrate and ammonium concentrations being higher than the Hungarian average. Since the prevailing wind in the area is north-west, the pollution probably comes from Slovakia, from the industrial area west of Rozsnyó.

Heavy metals can settle from the atmosphere by dry or wet deposition, and in wet agent, with adequate pH conditions they become mobile and can enter the karst water system. On the Slovakian side of the karst, in Pelsőc, there was a galvanizing factory for decades. This factory was closed down in the early 90's. That brings up several questions: what kind of metals was the factory using as catalyst for producing galvanized metals? Could these catalysts get into the atmosphere and to the entrance of the Domica cave, only 6 kms from the spot? If they did, what effects did they have over the last years?

The other potential pollution source is Rozsnyó and the industrial area surrounding the city.

Pollution can get to the territory not only by deposition from the atmosphere but also by infiltration from the surface. In August 2002, between the Hungarian-Slovakian border and the Slovakian settlement of Hosszúszó (Dlha Ves), in the Domica-Baradla cave system's catchment area there were 3-4 heaps of building debris and communal garbage left by the road which could also be a potential pollution source.

Some of the water from the Kecső stream that issues by the Slovakian settlement of Kecső (Kecovo) gets to the Jósva spring so the communal waste in the stream channel is also to be considered an important pollution source (*Sásdi,* 1998).

Another problem can be the agricultural activity, cattle farming and gardening in the large catchment areas of the sinkholes both in Slovakia and around the Hungarian settlement of Aggtelek. Contaminants get to the karst water directly through the sinkholes or with the thermal waters moving through pannon loamy gravels (*Sásdi,* 1998). This is also true to the waste yard that was active a few years ago about 1 km south of the settlement. This source endangers mainly the waters of the Jósva spring.

CONCLUSION

These are just preliminary results and provide information about the actual stage. It is absolutely necessary to continue the investigation since the heavy metal pollution of the karst waters providing drinking water for the population can cause serious health problems.

The examination is part of the research that aims to analyse the heavy metal pollution of the soil and plants of the karst areas. If the pollution of the soil, plants and the water prove to be interrelated, it outlines a future environmental protection duty for the landscape management.

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THE ROLE OF FORESTS IN THE KARSTECOSYSTEM

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Összefoglalás: A növényzet összetételét és növekedését egy adott helyen a környezeti tényezők közötti kölcsönhatások határozzák meg. A magyarországi karsztterületek természetes vegetációja az erdő. Az erdődinamikai folyamatok, és az ezeket befolyásoló emberi tevékenység alaposabb megismerése hasznos eszköznek bizonyulhat a gyorsan változó, érzékeny karsztos ökoszisztémák kutatásában.

Abstract: The composition and growth rate of vegetation is defined by an interaction between the environmental factors and therefore can be considered a result of these interactions. In Hungarian karstlands the natural vegetation is forest. A better understanding of forest dynamics might prove a useful tool in the research of the fast-changing, sensitive karstecosystems.

Keywords: Forest, karstecosystem, tree growth, Aggtelek National Park

INTRODUCTION

The claim to understand the wider context of the karsts' environment only appeared in the last few years. Vegetation is one of the karstecological factors as described in *Kevei-Bárány* (2004). As such, it interacts with the other factors of the karstecosystem: it directly affects microclimate and soil and thus indirectly the whole system; meanwhile the composition and growth rate of vegetation is basically defined by the very same factors. The composition and growth rate of vegetation can be considered a product of the interaction between the karstecological factors therefore investigating these characteristics can lead to a better understanding of karst processes and provides a unique possibility of monitoring.

According to the natural vegetation map of *Soó et al.* (1999) the potential vegetation of Hungarian karstlands is mixed-stand deciduous forest. Despite the vegetation having been affected for centuries by human activity, the proportion of woodland in these areas is still relatively high as opposed to lower-elevation parts of the country (*Fig. 1*). In order to use this information in karst research, we need to develop a deeper knowledge of the natural dynamics of forests and the anthropogenic activities affecting them.

The extension and state of the forest today is defined by forest management which means silvicultural activity has an impact on the whole karstecosystem through changing the forest and the production site. The extensive use of wood as fuel or building material has been present in our mountain areas since the 15th century, but conscious forest management in Hungary started only in the late 19th century. Therefore a thorough knowledge of old forest management methods is extremely important because silvicultural practise defines the state and extension of a forest for centuries. Land owners and foresters have been interested in forest growth characteristics early on as their income depended on having the right type of forest at a specific production site. In some areas forest management plans date back to the early 20[th] century and besides tree volume data they provide complementary information on the species composition, soil and water balance of the production sites. Foresters' data and practical experience gathered over such a long period might be of help in understanding the ongoing processes of karstlands.

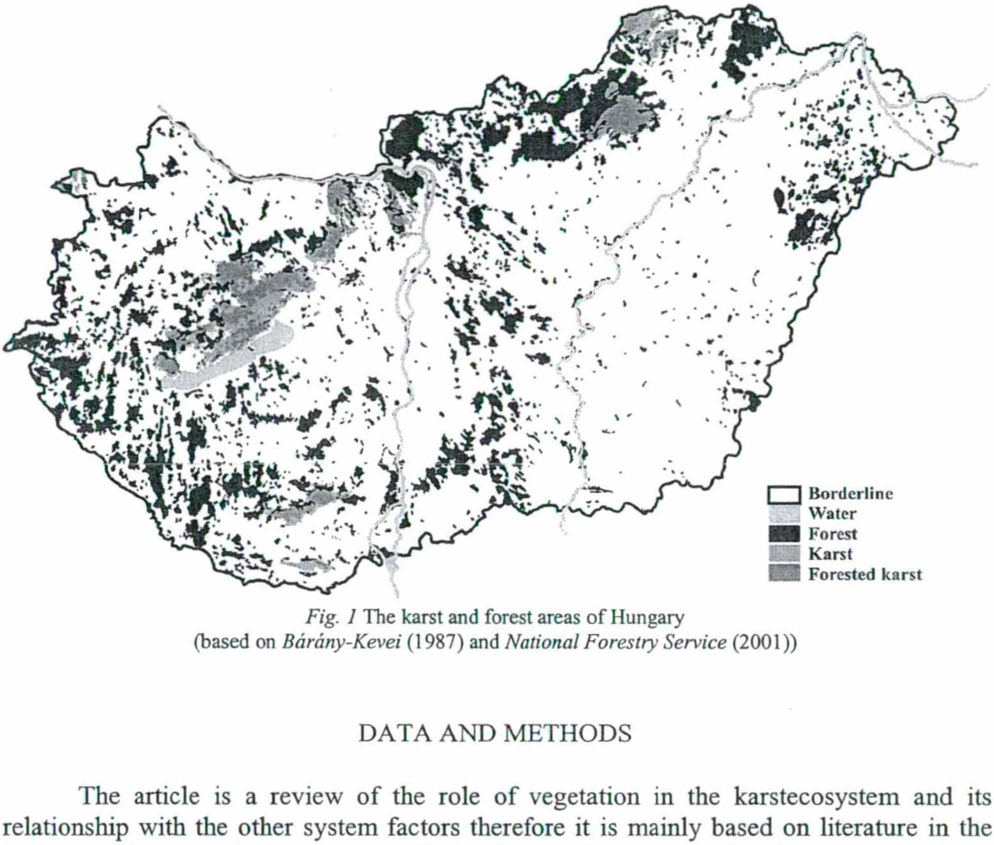

Fig. 1 The karst and forest areas of Hungary
(based on *Bárány-Kevei* (1987) and *National Forestry Service* (2001))

DATA AND METHODS

The article is a review of the role of vegetation in the karstecosystem and its relationship with the other system factors therefore it is mainly based on literature in the field of ecology and forestry. To provide local examples I also used GIS data derived from forest management plans of Aggtelek National Park from the year 2001 and some additional data from the National Forestry Inventory.

DISCUSSION

Functions of the forest ecosystem

Although there are no data available on the extension and attributes of forests in karst areas, a look at the two maps in *Fig.* 1 suggests that some of the largest continuous woodland in Hungary can be found in our karst mountains. The importance of forests in conservation and environment protection is well described by the fact that while the proportion of forested land in Hungary is only 19%, 49% of nationally protected areas are forested (*Exner and Jávor,* 2003).

Forests have several important functions. Some of these are gaining importance these days when the increasing human impact on nature becomes a major issue.

They play a significant part in balancing the nutrient and water cycle. In karst areas the latter function is even more important as karst rock types are water-soluble; this means there's an additional loss of water on the surface, due to infiltration into the rock base.

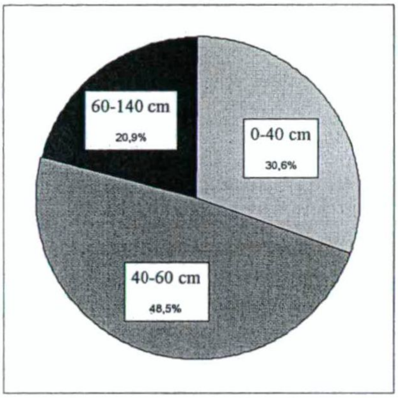

Fig. 2 The proportion of soil depth categories in the forests of Aggtelek National Park

Forests' role in erosion control was already recognised in the early 19th century (*Járási,* 1997) and protection measures were taken, with more or less success. Many forests owe their existence to the fact that karst soils are generally shallow and thus unsuitable for growing crops. *Fig.* 2 represents the proportion of soil depth categories in Aggtelek National Park.

Forests are the sole sources of wood, which is widely used as fuel, building material or paper. Forests growing on shallow karst soils do not, as a rule, provide quality wood. Karstlands being environmentally sensitive areas, their forests are often designated protection as primary function (*Fig. 3*). Wood production is limited or forbidden in such forests but they are valuable as habitat and places for recreation and tourism.

Last but not least, an equally important function of forests is to provide favourable conditions for maintaining their own continuous existence. One could argue whether this is ability or function but human interference disabling it often causes all the other functions to be temporarily or utterly disabled as well.

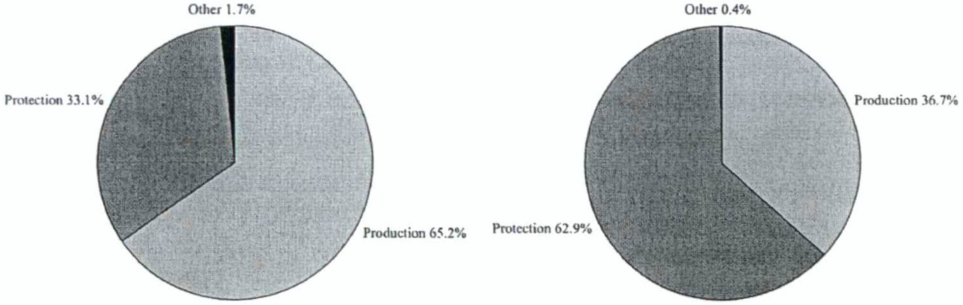

Fig. 3 Left: Primary function of the forests in Hungary in 2001 (*National Forest Inventory*, 2001)
Right: Primary function of the forests in Aggtelek National Park in 2001

Interactions between the forest and the other karstecological factors

Comparing *Fig. 4*, which presents the structure of the karstecosystem (*Keveiné Bárány,* 2004), with *Fig. 5*, that describes the interactions between environmental factors influencing tree growth, the similarity of the factor groups becomes evident. As it is the major system factors of the karstecosystem that directly define the state of the vegetation, the composition and growth rate of vegetation can be considered the result of the interaction between the karstecological factors. Therefore they can be used as an indicator of changes in the system.

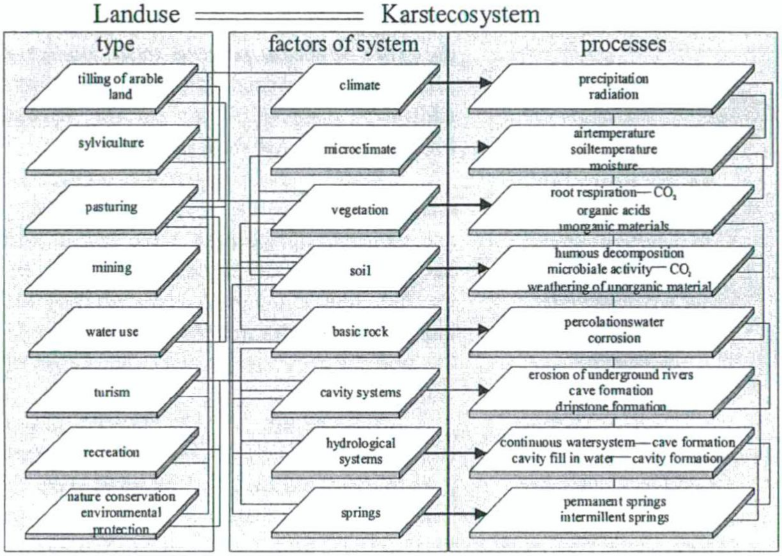

Fig. 4. The karstecosystem (*Keveiné Bárány*, 2004)

The generally shorter life cycle of herbaceous plants means that their species composition is quickly modified according to the changing environment. Meanwhile arboreal species adapt to changes by means of their genetic diversity and in stand by creating an optimal environment. Changes in the surrounding environment affect their growth and health, in extreme case their mortality or survival but changes in their species composition are much slower. General preferences and possible indicator roles of different plant species in Hungary have been thoroughly examined by *Zólyomi et al.* (1967) and *Borhidi* (1993) so this article concentrates on the possible role of tree growth rates in karst research.

Both agricultural research and plant ecology extensively investigated the correlations between environmental factors and plant life. Direct observational approach did not usually bring success, because usually the actual

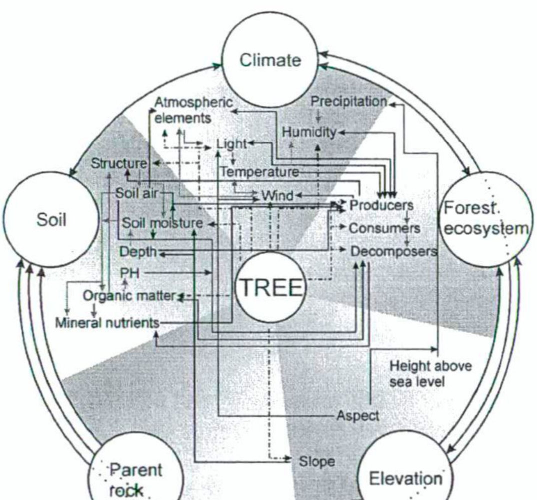

Fig. 5 The environmental factors affecting tree growth (original)

outcome (survival, fatalities, growth rates, etc.) is a result of the interaction between the factors (*Grime,* 1991). So this kind of research often consists of the investigation of one factor within a controlled environment (*Füleky and Tolner,* 1999). The emphasis obviously lies on the preferences of crops and other cultivated plants; however, trees' and stands' responses to a range of environmental factors have also been studied. Yet, due to the wide range of environmental factors and their complex interactions, the resulting mechanistic detail is often difficult to translate into practical application (*Long et al.,* 2004).

Factors affecting tree growth and vegetation composition

Fig. 5 is a simplified description of the relationship between factors affecting tree growth. The drawing and the commentary is based on *Tompa* (1975), *Botkin* (1993), *Debreczeni* (1999), *Láng* (2000a, 2000b) and *Simon* (2000). I formed five classes of factors: parent rock, elevation, soil, climate and biosphere. Each class interacts with the others on a global and a local level. In the drawing global interactions are described by the surrounding arrows. Though these essentially define the environment and the possibilities of plant life, the really important relationships work out on a local level, represented by the arrows within the circle. I did not include the anthropogenic factor in the drawing because despite affecting each of the factors, human activity doesn't influence the way of their interactions. Hydrology could be viewed as a sixth class but the different parts of the hydrological cycle are closely related to the existing factor groups and were consequently defined as their part.

Climatic factors

Temperature affects tree growth by changing the rates of enzyme reactions and so it defines the rates of photosynthesis. By defining humidity it affects the rate of transpiration. High soil and air temperature dries the soil and leads to drought effects on trees (*Botkin,* 1993). Heat increases transpiration and if the rate of transpiration exceeds the rate of photosynthesis for a longer time, the tree will perish (*Láng,* 2000a). The thermal characteristic most commonly used to describe the temperature preferences of different species is the heat sum. Extreme temperature conditions and their temporal distribution are also of major importance (*Tompa,* 1975). Temperature is essentially defined by the amount of available light. Forests affect temperature by limiting the amount of available light and changing wind speed and direction.

Sunlight provides the energy needed for the evaporation of water and makes possible its transport from the roots to the leaves (*Botkin,* 1993). It is the basis of photosynthesis so it directly affects the rate of plant growth. The available amount of light defines temperature which in turn defines transpiration. The need for light varies with species and age; geographical position and quality of the production site also affects the light tolerance ability of plants (*Tompa,* 1975). The available amount of light is defined by the amount of solar radiation and exposition (elevation). Forests directly affect the amount of available light by shadowing the ground with their canopy.

Many atmospheric elements affect tree growth. Oxygen is the source of energy for all biological processes, needed for plant transpiration while atmospheric CO_2 is the main source of organic matter production (approximately 50% of the trees' dry matter consists of C – *Tompa,* 1975). An increase in CO_2 concentration increases the rate of assimilation. Oxygen is a product of photosynthesis while CO_2 that of transpiration so their local concentrations are directly affected by the type and structure of the forest. Nitrogen is a basic structural element of organic compounds, it plays a vital role in the formation of protein and thus the amount of available nitrogen significantly affects growth rate. Too high N-concentrations lead to a decrease in yield and quality (*Debreczeni,* 1999). Most of the nitrogen comes from the atmosphere and becomes available to plants through biochemical fixation by bacteria. Certain plants (i.e the *Fabaceae*) form symbiotic relationships with these so the presence of these plants results in higher soil nitrogen concentrations in their environment. Thus the amount of available nitrogen depends on the type of vegetation cover and the presence of nitrogen-fixing bacteria as well as the amount of nitrates settling from the atmosphere. Other elements (S for example) settling from the atmosphere can have either negative or positive effect on growth, mostly depending on the amount (*Debreczeni,* 1999). The concentrations of atmospheric elements are defined by the air movements, the quality and structure of the soil, modified by the type and structure of the vegetation cover.

Precipitation basically defines the water amount available to plants, even though it is humidity and the water content of the soil that actually influence tree growth. Water is essential for photosynthesis (as the source of hydrogene in primary organic matter production) and transpiration; it is the medium for biological processes within and outside of living organisms (*Simon,* 2000). It is water that enables plants to keep their cells in turgid state; it provides the means for element transport within the tree and facilitates the intake of nutrients (*Tompa,* 1975). The climate and the elevation define the amount of precipitation.

Humidity affects the rate of evaporation and transpiration; it is defined by the amount of precipitation, and modified by evaporation from the canopy (interception) and the transpiration of plants (*Simon,* 2000).

Besides affecting temperature and the atmospheric concentration of different elements, wind plays an important part in the reproduction processes of many trees. It helps the spreading of these species and thus has a major role in natural reforestation. Strong winds may distort trees or even cause windfall; the leaf cover of the forest floor or the surface air with higher CO_2 concentrations (essential for photosynthesis) can be flown away (*Tompa,* 1975). Wind also increases the rate of transpiration by affecting humidity. Macroclimatic conditions and the elevation essentially define wind speed and direction. However, forest cover can significantly modify both.

Elevation

As elevation defines a lot of the other factors its indirect effects on growth are of major importance. Aspect defines microclimate. The steeper the slope, the greater the angle of radiation and consequently the temperature's higher. On steep slopes, a greater amount of water is lost as runoff and therefore less is available for plants; also the soil profile is less deep and nutrients are washed out. The stability of the slope directly affects the possibility of plant colonisation; meanwhile the presence of vegetation enhances slope stability. Parent rock and climate basically define elevation and vegetation cover also affects it to a lesser extent.

Parent rock

Parent rock does not directly influence tree growth (except under very special conditions) but it defines soil, elevation and hydrological conditions and thus should be included in the model.

Soil

Apart from physically limiting the size of roots the depth of the soil profile affects the water and heat balance of soils. This soil characteristic depends on the parent rock, the climate, the original material and the elevation.

Soil structure affects soil air and moisture; compressed soil acts as physical obstacle to the roots (*Tompa,* 1975). Soil structure is affected by the vegetation cover, and microbial activity.

Soil air is essential for microbial and root transpiration. Its oxygene concentration affects microbial activity and thus defines mineralization processes. Vegetation affects soil air by root transpiration and by modifying the soil structure.

Though precipitation basically defines the water amount available to plants, soil moisture is of primary importance. Additional water may become available by subsurface runoff or through upward capillary action. Water may be lost through percolation, runoff or evaporation from the soil. Soil moisture is defined by soil structure, precipitation and slope; it is also affected by the plants taking up water, which is eventually transferred to the atmosphere by transpiration from the leaves (*Botkin,* 1993).

The pH value of a soil defines nutrient availability for plants. In extreme cases toxic materials normally not available to plants become uptakeable (*Láng,* 2000b). Forest plants modify the pH of a soil by providing organic matter of different quality. So the pH of a soil basically depends on the type of parent rock, climate but it's also influenced by the type of vegetation cover.

Organic matter positively influences soil properties. Its quantity depends on the available dead material and the intensity of microbial activity.

Mineral nutrients are needed for the production of different molecules in living organisms. Each plant species needs different amounts of these so their presence affects species composition. According to *Grime* (1991), besides having a dominant effect on the quality and quantity of phytomass, they also control the rates of both cyclical and successional vegetation change. The different concentrations of these elements in different plant species affect the nutrient content of the soil after the death and decomposition of the plant. Thus the nutrient content of the soil is defined by parent rock, elevation and the type of vegetation cover.

The forest ecosystem

Only plants are capable of primary organic matter production so they are the producers, the basis of the food pyramid. All the plants in a forest are each other's competitors in the contest for resources; meanwhile they continuously form their environment, which in turn leads to a constant dynamic change in the composition of the vegetation. Some plants have a direct effect on others by emitting material that prevents their reproduction but mainly they affect each other indirectly by defining the amount of available light and the nutrient content of the soil.

On the higher levels of the forest food web consumers upkeep the nutrient cycle, define plant species composition and the soil structure; they play a vital role in the reproduction of certain tree species. Some (i. e. mycorrhizal fungi, nitrogen-fixing bacteria, etc.) living in symbiotic relationship with plants provide a critical linkage between the plant root and soil and thus enable them to tolerate environmental stresses better. A propagation of primary consumers (i. e. *Ips typographus, Lymantria dispar*, etc.) often results in the destruction of large forested areas. Such events are partly natural and partly due to the selective removal of parts of the forest food web. Some consumers are species-specific while others polyphag, nevertheless it is the vegetation composition that essentially defines the presence of consumer species.

Decomposers break down dead organisms and thus define the nutrient content of the soil. Decomposer activity is affected by the soil properties, especially soil air and the amount of organic matter.

The need for different resources is species-related and besides the necessary amount, temporal distribution is also of importance. All the factors are highly varied both in a temporal and spatial sense and there's no general definition of their relative importance because even this changes over time and space. Easiest to detect are the effects caused by the abundance or lack of one factor, if all the others are available in sufficient quantities (*Füleky and Tolner,* 1999).

Similarly to ecologists (although driven by economic interests) foresters have also long been involved with the research of environmental factors affecting tree growth. Based on their field experience and long-term observations (without much knowledge whatsoever of the processes leading to the result of their observation) they also realised it was not the factors or any of their attributes that defined plant growth but it was a result of the interaction between them (*Járó,* 1972). They named the site-specific result of this interaction production capacity. In the 19th century 6 productivity classes were defined which summarize the quality of the production site as a single index. The relationship between yearly tree volume increment and these productivity classes was verified with statistical methods a century later by *Bán* (1996). Of the wide range of factors a few have been selected that have a critical influence on tree growth and are also easy to measure or define in the field: genetic and physical soil type, depth of soil profile, height above sea level, slope, aspect, water excess and climate. (The latter describes average humidity of the site at 2 pm in July). These attributes of the production site are included in forest inventories and management plans, refreshed once every decade. Thus, these management plans provide valuable historical data and, to a limited extent, can be used for long-term monitoring purposes.

Tree growth as an integrator of the karstecological processes

The relationships described above suggest that besides examining the vegetation composition, measuring tree growth rates might prove an important tool in monitoring the karstecological processes as these rates provide information on the operation of the whole system. *Long et al.* (2004) argue that tree leaf area is the best integrator of the ecological processes affecting resource capture and carbon assimilation. However, in the case of Hungarian karsts the use of tree height and complementary field diameter measures would also be recommended because such data are available for the last 50 years for every forest stand and could be used as reference. According to *Botkin* (1993) tree growth is basically '*the net accumulation of organic matter and is therefore the difference between the amount of new organic matter produced by the leaves and the amount used by the rest of the living tissues*'. His fundamental growth equation expresses tree volume as proportional to the square of the diameter times the height. Volume could be replaced with either the diameter or the height as they are directly proportional. Diameter is easy enough to measure in the field but tree height data can be more simply acquired en masse using remote sensing techniques (*Bán,* 1996). Using Digital Surface Models created from air photography negatives enables digital tree height measurement with an accuracy of approximately 1-1.5 m (*Zboray and Tanács,* 2005). Using old photos time series can be created especially that additional information (species, age, and productivity class of the stand) indispensable for the analysis is available in the forest inventories. There are also empirical relationships defined for age, height, diameter and volume for each economically important species in every productivity class.

Forest management and its effects on forests – the example of Aggtelek Mountains

The use of forest growth as an indicator of changes is limited by the fact that at present there are no natural forests left in Hungary. Species composition, age structure and health conditions are all defined by forest management practices which aim to maximise quality wood production and, in order to achieve this, to ensure the dominance of certain tree species.

The history of forest management throughout Europe can be basically divided in two main periods: the age of forest use, and recently, the age of conscious forest management. However, the extension or reduction of woodland area has always been a function of landowners and their momentary economic interests (*Járási,* 1997). Throughout history regulations and laws could only influence forest use if they actually triggered economic interest.

In the Aggtelek area the period of simple forest use lasted from the appearance of humans till the beginning of the 19th century. It was mainly a period of deforestation; forest products (timber, herbs, berries, acorn, etc.) were gathered and used without any care for replacement and regeneration. Some species, like for example sessile oak (*Quercus petrea*), mostly characteristic of later successional stages, provided quality wood, represented higher value and were therefore widely used. After being cut down, frequent grazing prevented their natural regeneration and their place was taken by less seeked-out species with a better ability to tolerate disturbance and grazing (*Járási,* 1997; *Bartha,* 2001). This period defined the possibilities of forest management later so today's processes have their roots in the changes that occurred in these historical times.

The period of transition from forest use to forest management lasted more than a century. Despite the need for sustainable management being recognised, there was no significant change in the actual silvicultural practices because of the unfavourable macroeconomic environment. The first half of the 20th century included two world wars and a global economic crisis. Hungary lost most of its forests; the forests left often meant the only income to their owners (*Járási,* 1997). The current age construction (*Fig. 6*) clearly shows that this period almost finished off the last remnants of forests in the Aggtelek area. After the world war, political changes resulted in the forests being taken into state management and a new era began. Regeneration works immediately started in order to satisfy the wood claim of post-war reconstruction.

In an ideally managed forest, there could be no distinction made between final harvest and regeneration, but the forest cover should be (at least on a large scale) continuous, both in space and time (*Sódor and Temesi,* 2001). But forest management methods were invented to handle a significantly disturbed ecosystem. Forests have their own responses to handle these disturbances – secondary succession (*Standovár*, 2000). In the Aggtelek area, it was the spreading of hornbeam (*Carpinus betulus*) that prevented irreversible erosion and the final disappearance of forests from large areas in the early 20th

century (*Gencsi and Vancsura*, 1992; *Járási*, 1997). Today's high proportion of hornbeam in the area's forests is the witness of earlier forest use (*Fig. 7*).

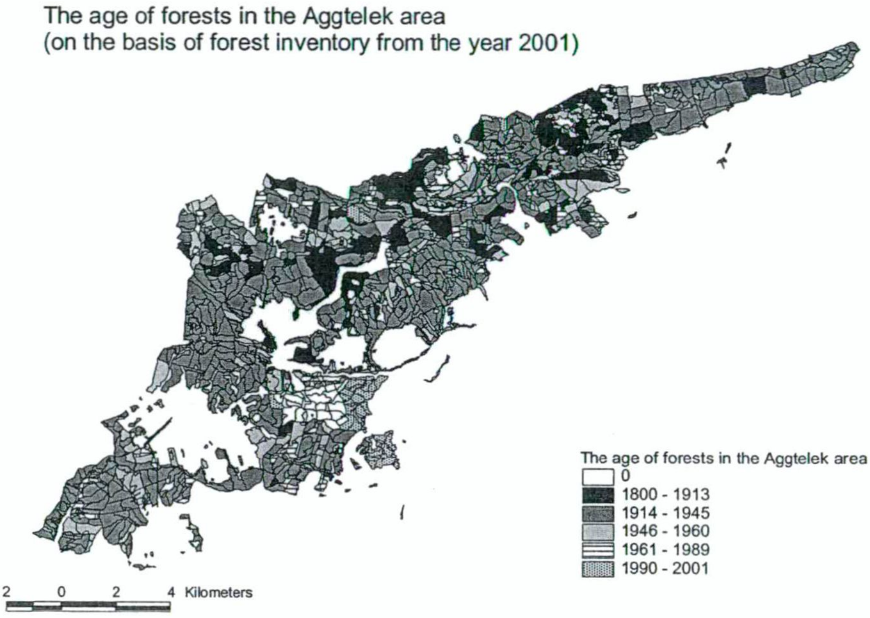

Fig. 6 Year of plantation – the age of forests in Aggtelek National Park

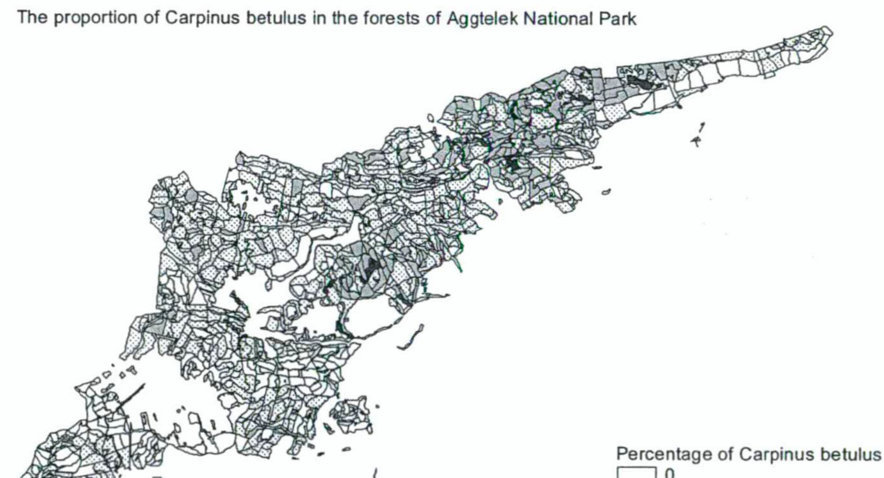

Fig. 7 The proportion of hornbeam (Carpinus betulus) in the forests of Aggtelek National Park

However, the claim for wood has always been too great to allow waiting centuries for the formation of another climax association. Felling cycles were and are much shorter than the lifetime of most tree species and this leads to frequent anthropogenic disturbance. According to *Long et al.* (2004) stand regeneration practices are usually intended to create conditions that favour early dominance by one or more desired species. In the Aggtelek area, it would be long-lived, slow-growing deciduous tree species (mostly oak species) which provide the most valuable wood. However, as *Grime* (1991) argues, '*non-equilibrium systems encourage plant species with high potential growth rates. (...) Under the impact of increasing habitat disturbance and eutrophication, the composition of vegetation is becoming more dependent upon the rates at which nutrients are captured and less upon the capacity to tolerate particular nutrient limitations'*. These conditions do not favour the above mentioned species. To resolve this contradiction modern forest management chose to even more drastically interfere with the forest ecosystem. Faster-growing, undemanding, often coniferous foreign species were planted to shorten the felling cycle or to reforest sites affected by erosion. Site preparation after clear-cutting often included harrowing, which completely removed understory vegetation. Some species were considered harmful or simply useless and consequently often removed along with their specific fauna. That decreased both structural and species biodiversity which in turn led to the weakening of the ecosystem's self-regulating function. In today's profit-orientated management, drastic forest treatment methods vary from clear-cutting to the extensive use of chemicals in order to control competing vegetation and consumer fauna. Such interferences cause the natural processes of forests to become homogenous (*Standovár,* 2000). Managed forests do not interact with the other factors of the karstecosystem anymore, rather one-sidedly affect them. The removal of the forest cover results in extreme temperature fluctuation in the dolines (*Keveiné Bárány,* 2004) which in turn limits reforestation. Wood production directly affects the nutrient cycle by removing nutrients stored in the trees (especially in case of coppice woods) and indirectly by increasing surface runoff which in turn increases erosion and washes out nutrients from the soil. Modifying species composition changes soil properties; non-native coniferous forests cause a decrease in pH that modifies the availability of nutrients and toxic material (*Berki*, 1999).

These are just a few examples of the effects of silvicultural practice on forests and their environment; but through the relationships shown in *Fig. 5* any kind of human interference affects each factor of the karstecosystem. Thus, when trying to investigate forest dynamics and their relationship with the environment, it is essential to take into account the forest management practices of the study area.

CONCLUSION

In this article I reviewed the relationship between the karstecological factors partly to represent the complexity of their interactions and partly to demonstrate how easily the whole system can be affected through modifying one single factor: the vegetation. In Hungarian karstlands the natural vegetation is forest. Forests have several important functions which may gain special significance in areas as environmentally sensitive as the karsts. However, the forest ecosystem has been affected by human interference for centuries, so in trying to better understand the functioning of the karstecosystem, it is essential to know the methods of forest management and their possible impact.

The forest ecosystem affects and is affected by the other factors, consequently its composition and growth rate can be considered a dynamic result of their interactions (modified by human impact). Herbaceous plant composition reacts quickly to environmental changes while changes in arboreal species composition are rather slower; however, tree growth rates can also provide information on these changes. Tree growth rates can be described by – besides other methods – a yearly volume increment which can be defined by diameter and height measurements. Besides being simple and cheap these measurements have the advantage of being comparable to unique historical data in forest inventories and management plans and are thus suitable for conducting investigations of long-term environmental change.

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DEFINING THE CORROSION SURFACE OF THE DOLINES BY MEANS OF A DIGITAL ELEVATION MODEL

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Összefoglalás – A karsztmorfológia kutatások egyik fontos területe a karsztok jellegzetes formáinak, a dolináknak a sokirányú vizsgálata. A karsztok változatos felszíne, a dolinák alakjának egyedi vonásai megfelelő pontossággal csak szabatos térképészeti eljárások, és teljes körű új felmérés segítségével elemezhetőek. Digitális domborzatmodellek alkalmazása lehetőséget ad a lejtőkategória vizsgálatára, aminek segítségével a felszín valós nagysága (összehasonlítva a felszín síkba eső vetületével) számítható.

Summary – The complex study of most typical karst features, the dolines, forms an important part of karst morphological research. The varied surface of the karst, the individual shapes of the dolines can only be analysed with the help of proper cartographical methods and a holistic approach. The use of dipital elevation models provides pssibility to compőute the precise slope values and trough these to specify the real area values of the surface (as opposed to the area in projection).

Key words: karst doline, surface, GIS, digital elevation model

INTRODUCTION

A complex investigation of the dolines, the most typical features of karsts, is an important domain of karst morphological research. In earlier investigations of the dolines (*La Valle* 1968; *Zámbó* 1970; *Jakucs* 1971; *Ford and Williams* 1989; *Veress and Péntek* 1990; *Castiglioni* 1991; *Bárány-Kevei and Mezősi* 1991; *Farsang and Tóth* 1992; *Hoyk* 2002; *Telbisz* 2003; *Péntek and Veress* 2004) morphometric parameters were defined either on the basis of field observation and measurement, or topographic maps, GPS and total station measurements. The highly varied surface of the karsts, the unique shapes of the dolines in a large area can only be measured and analysed with the appropriate precision by means of proper cartographic methods and a complete new survey.

Digital elevation models are more and more often used for the measuring and representation of elevation data. The available databases (e.g. SRTM) can be well used to describe karstic macrofeatures, on the condition that they are properly extended (*Telbisz* 2004). In an earlier study we showed the extent of differences between the elevation model of the study area (Bükk-plateau) created from available topographic maps and the model of the same area derived from more reliable large-scale aerial imagery by photogrammetric methods (*Zboray and Keveiné Bárány* 2004). In order to carry out analysis on the digital elevation model, it is necessary to precisely define the extent of the dolines, which we described by taking the most external closed contours for boundary.

The advantage of using the most external closed contours as boundary is that it provides a good opportunity for comparison though it is subjective to a certain extent because the dolines do not usually end in the same plane. Another reason for the use of this definition is that in earlier doline morphometric research the height difference between endpoints was not defined when measuring different parameters, like for example diameter. This problem of the dolines' area was also investigated by *Telbisz et al.* (2005), who extended the boundaries to include the dolines' catchment area.

METHODS

Data acquired by remote sensing techniques increasingly gain ground in karst research. The field-photogrammetric measurements of *Tóth and Schläffer* (2004) on karrs proved that this method – combined with field measurements – provides more precise information.

The classic photogrammetric methods we use create stereo-models from aerial images which are suitable for the measurement of height data by stereo-photogrammetric instruments. The advantage of this method is that – when using the appropriate scale – it enables the user to analyse and assess large areas. Aerial images are available of any Hungarian area from different years since 1950 because of the periodic map-revising programs of the last fifty years.

Using the above mentioned GIS database of the Bükk-plateau we interpolated a contour map with 0,5 m intervals (for comparison: the base contour interval of topographic maps is 5 m). Within the limits of the most external closed contour we defined 275 dolines and we created the digital elevation model of the area.

DISCUSSION

In a GIS environment – with the help of the *LEICA ERDAS IMAGINE Slope application* – there is a possibility to quickly define slope categories. Each cell of the slope map contains the slope angle as an attribute (*Fig. 1*) The size of the cells is 2x2 m.

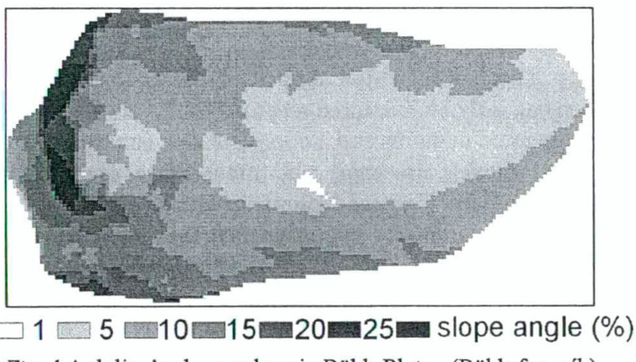

Fig. 1 A doline's slope values in Bükk-Plateu (Bükk-fennsík)

Considering the morphometric parameters of a doline the area of the feature is of utmost importance. It can be approximated with an ellipsoid shape, by measuring the two axes in the field. On a topographic map, contours can be used to define the doline's boundaries but this method, due to the above mentioned reasons, may be highly inaccurate. All of these methods only measure the projected doline area.

Because of the complex spatial form of dolines, their shape and corrosion surface could only be computed using mathematical formulae, considering the doline to be approximately of the shape of a spherical calotte (*Keveiné Bárány,* 1981).

Even in the case of area measurements carried out on digital elevation models (DEM) we must consider that the cells of the DEM represent the projected points of the surface as well. The advantage of this is that DEMs can be compared with different maps of the same projection; however they do not directly provide information on the surface. Yet as the slope angle in each grid point is known, the real surface can be computed in these points (*Fig. 2*).

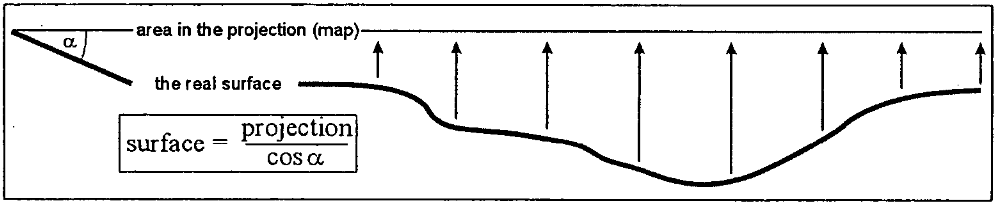

Fig. 2 The computation of the real surface at a point of the doline (cross-section)

The advantage of this method is that by editing the attribute tables, the surface can be computed with any GIS-related software which is able to handle digital elevation models. Besides GIS software there are certain special applications which can directly measure surface (*Telbisz et al.,* 2005)

All GIS data, be it point, line or polygon data, contain an attribute table presentable and editable by even the simplest GIS software. In this attribute table, similarly to Excel tables, we can assign functions to the columns or fields.

In the case of the slope map's attribute table the area belonging to a given slope angle is the frequency times the regular grid size (4 m^2). By assigning the formula shown in *Fig. 2* the function of a new column, the real surface area belonging to the given slope angle can be computed (*Fig. 3*). These areas added up equal the real surface of the doline.

Slope	Frequency	Area	Surface
0	36	0.0144	0.0144
1	487	0.1948	0.19483
2	841	0.3364	0.336605
3	587	0.2348	0.235122
4	324	0.1296	0.129916
5	437	0.1748	0.175468

Fig. 3 Inserting the real surface function to the slope attribute table

RESULTS

Using the method described above we computed the real surface area of the 275 dolines of the study area. The result was 1.2397 km^2 as opposed to the 1.2139 km^2 of the projected area so in the case of the Bükk dolines by using this method we get an average 2.13% extra compared to the area measured on maps. Because of the large number of elements we suppose that the proportion of the real surface to the projected area would probably not change significantly if we measured more dolines in the area.

By grouping the differences of real surface and projected area by slope angle values we find the highest values in the case of 15-16 degree slope angles. The gradient, shape and maximum of this surface-addition graph would probably be different in other karst areas. (*Fig. 4*)

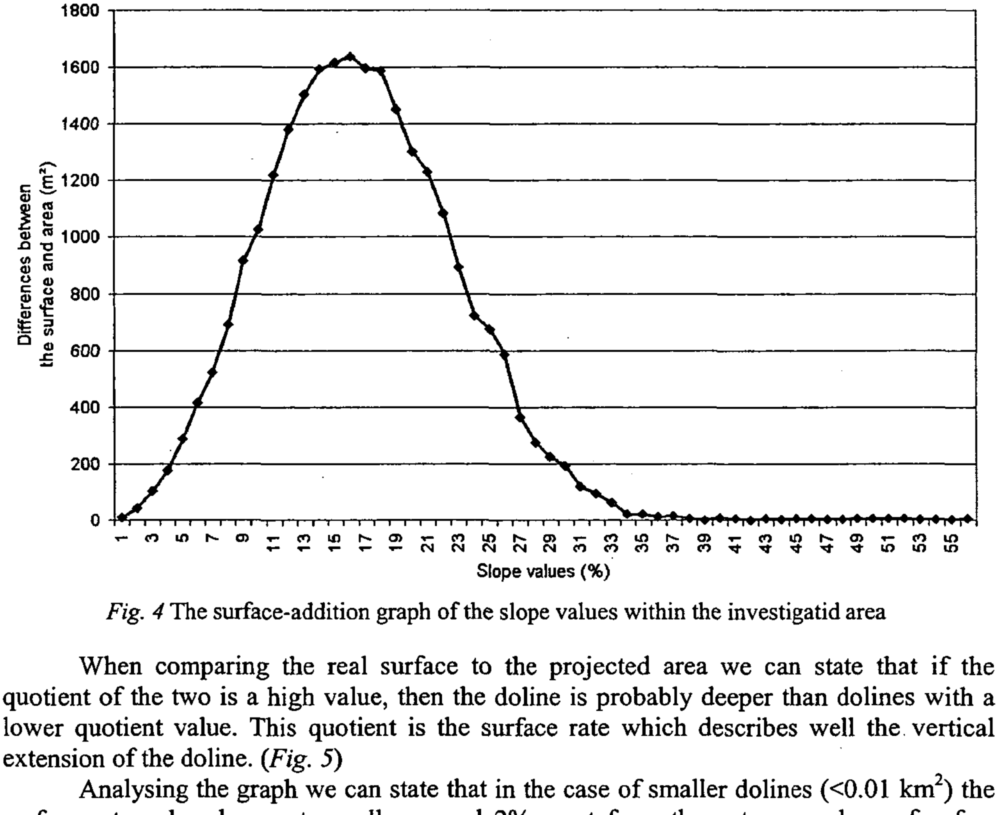

Fig. 4 The surface-addition graph of the slope values within the investigatid area

When comparing the real surface to the projected area we can state that if the quotient of the two is a high value, then the doline is probably deeper than dolines with a lower quotient value. This quotient is the surface rate which describes well the vertical extension of the doline. (*Fig. 5*)

Analysing the graph we can state that in the case of smaller dolines (<0.01 km^2) the surface rate value does not usually exceed 2% apart from the extreme values of a few dolines on the plateau. The bigger dolines (>0.01 km^2) can be characterised by an increasing surface rate though the values are rather varied. Finally the biggest dolines of the study area show a decrease in the surface rate probably due to gravitational mass movements which facilitate the widening of the doline by flattening out the steep slopes (*Telbisz,* 2003). On the basis of these samples we could not establish a significant relationship between the surface rates and the spatial distribution of the dolines, apart from those situated on the plateau. This result does not exclude the possibility that such relationship could be established by further investigations (and different sampling methods). Yet depth characteristics basically describe the unique shape, structure and microclimate of the doline along with the circumstances of formation.

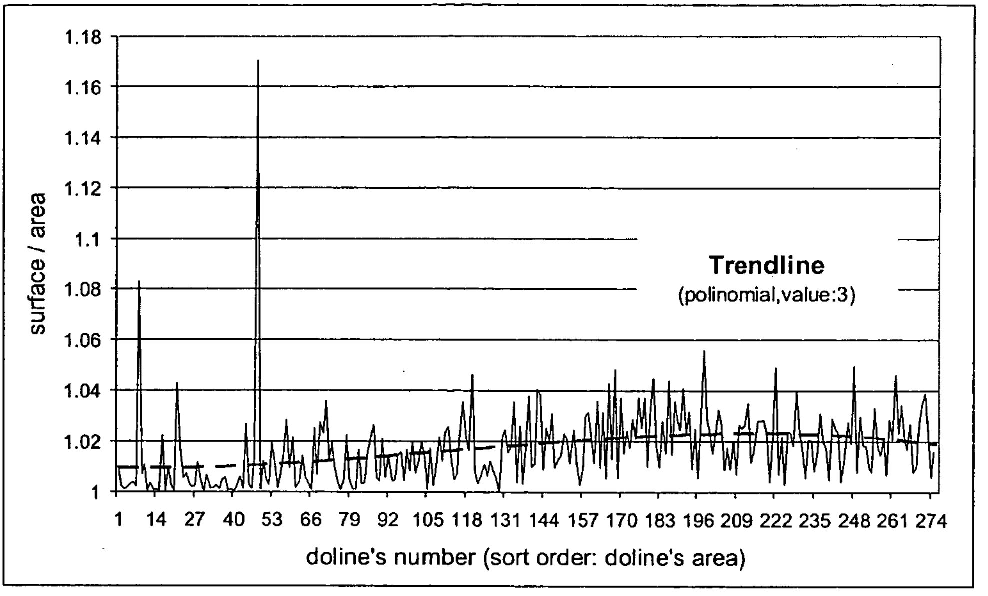

Fig. 5 The dolines' surface rate within the investigation area

CONCLUSION

- The measurement of a large number of dolines in a large area is possible with the use of digital elevation models. The real surface can be computed by defining a function in the attribute tables of the slope map derived from the DEM.
- In the case of the dolines in the Bükk-plateau study area the real surface values exceed the projected area by 2% (in extreme cases even by 17%).
- There is a relationship between the doline's extension, size and the surface rate (the quotient real surface/projected area) which is probably characteristic of each karst type.

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AN INVESTIGATION OF THE GROWTH TYPES OF VEGETATION IN THE BÜKK MOUNTAINS BY THE COMPARISON OF DIGITAL SURFACE MODELS

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Összefoglalás – A karsztok hasznosításának leggyakoribb hazai formája az erdőgazdálkodás. A fák növekedési ütemének ismerete kiemelten fontos az erdészeti hasznosítás számára, valamint jól használható a terület monitoringjához is. Vizsgálatainkban digitális felületmodelleket használtunk, melyet – a Bükki Nemzeti Park 100 km^2-es mintaterületéről 1965 és 2004. években készült légifelvételek alapján – digitális fotogrammetriai (SOCET SET) munkaállomásokon készítettünk. A digitális felületmodellek erdős területen tartalmazzák a famagasságokat is, így a felületmodell és a terepfelszín magasságának különbségeiből famagasság térképek készíthetők. A felületmodellek magasságkülönbségei a növekedésmenetek üteméről ad átfogó képet.

Summary – The most common form of land use in Hungarian karsts is woodland. The rate of tree growth in the forest is of utmost importance for forest management but it is also useful for monitoring purposes. In this study we review the possible uses of digital surface models (DSM) derived from aerial imagery in investigating tree growth rates. Two digital surface models were created of a 100 km^2 study area in the Bükk Mountains, Hungary by using aerial imagery from the years 1965 and 2004. Tree growth maps were created by extracting the areas' digital elevation models from these surface models. Our results suggest that these digital maps could replace field measurements in the future.

Key words: digital surface model, aerial images, tree growth, Bükk National Park

INTRODUCTION

The most common form of land use in Hungarian karsts is woodland. An integrated forest management taking into account considerations of environmental protection as well could insure the conservation of karsts in a near-natural state (*Keveiné Bárány*, 2004). Before World War II, the forests of the Bükk Mountains were owned by the state. While earlier the forests were mainly cut down to increase the area suitable for grazing, after the war deforestation followed due to a highly increased claim for wood production. The exploitation of forests also had an impact on their age composition. The foundation of the Bükk National Park in 1977 meant a turning point in the history of the area's forests, introducing the concept of sustainable management (*Keveiné Bárány*, 2003). In an earlier investigation we compared time-series of aerial photos in order to follow changes in the area. The species composition of the stands was defined by the supervised classification of Landsat satellite imagery (*Zboray and Keveiné Bárány*, 2002).

Most of the forests in the study area consist of European beech (*Fagus sylvatica*) which is usually cut down at the age of 120-130. *Bondor* (1986) summarized the relations of tree age and height in so-called yield tables. The main aim of the foresters' researches was to describe tree growth and changes in its rate. According to their results, the main differences in growth within a species can be shown in the case of young trees, because between the ages of 0-20 several factors can hinder growth. In this study we examine a 100-km^2 area of the Bükk Mountains (*Fig. 1*).

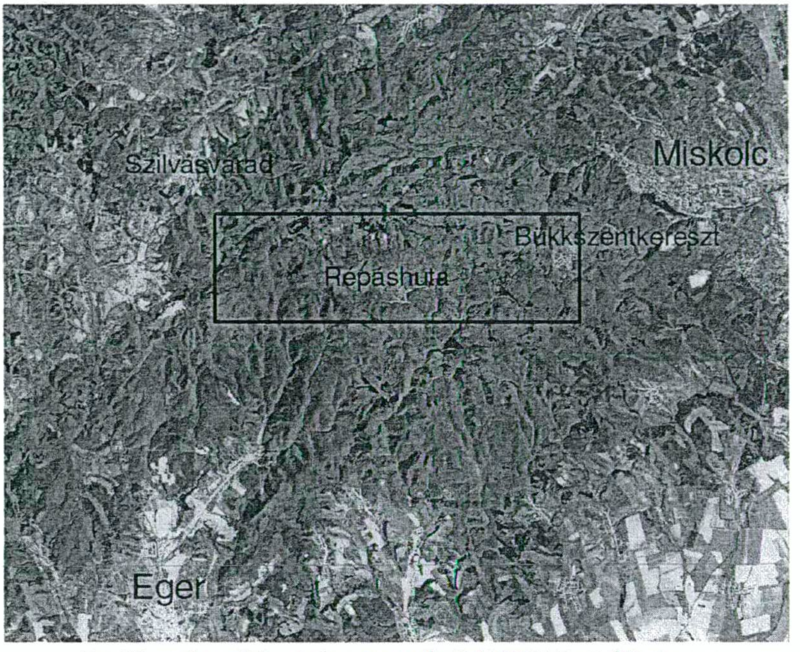

Fig.1 Location of the study area on the LANDSAT satellite image (Copyright ESA (1992), distributed by EURIMAGE, processed by FÖMI)

We reviewed the recent and archival aerial photos available of the area, provided by the Ministry of Defense Mapping Company. The aim of our investigation was to define tree heights and tree growth rates by means of photogrammetry and the visual analysis of the aerial photos in order to get information on the state and changes of the forest cover.

METHODS

Up to now defining tree height was only possible by field measurements. In the case of trees with a considerable height errors of several meters were common. *Bán* (1996) attempted to measure tree height in aerial photos. He took photos of the study area with and without canopy cover and then measured the height above sea level of the trees' apices and their root collars by photogrammetrical methods. He calculated the height from the difference of the two. The drawback of his method is the small number of measured elements, which means that the use of this method in the case of large areas is rather time-consuming.

Measuring tree height is also possible on spatial models created from satellite imagery. On the basis of LANDSAT and SPOT data *Donoghue et al.* (2004) found a root mean square error (RMSE) of 1.5 meters compared to field measurements. The most modern height measurements are conducted with lasers but the high expenses strongly hinder their use in Hungary.

In geographic information systems digital surface models created with digital photogrammetric workstations (SOCET SET) are spreading (*Fig. 2*).

Fig. 2 Digital elevation model (left) and the digital surface model (right) of part of the investigation area

As opposed to a digital elevation model, a digital surface model includes the height of natural and artificial objects on the surface as well as the elevation. The creation of a digital surface model is – as part of the photogrammetric workflow – automatic. A further advantage is that by processing archival photos we can gain information of the area from decades before. On the hypsometric image of the surface model – compared with the elevation model – the sites of clear-cuttings and logging by the roads can be clearly seen. For data processing and presentation we used the image-processing software ERDAS IMAGINE, as before.

Aerial imagery of the area was taken by the military cartographers in the years 1956, 1965, 1975, 1987-88, related to the revision of earlier maps. The most recent photos were taken in 2004 with a scale of 1:30,000. In order to compare with these we chose the photos taken in 1965 with a similar scale (1:32,000) which are of excellent quality – a crucial point in processing. Orthophotos created from the photos taken in 2004 and some ground control points measured by GPS served as the basis of the photogrammetric processing. Reliability is well shown by the root mean square error (RMSE) of the aerial triangulation, that is the following: X:0.433, Y:0.510, Z:0.460 (m), the total RMSE is 0.671 m. (In the case of a lot of measurements this is the theoretical average difference between the surface model and the real heights. In practice there can be 1-1.5 meters differences between model height and real height.) In the case of the photos from 2004: X:0.094, Y:0.089, Z:0.091 (m). The total RMSE is 0.146 m.

The creation of the surface model is only possible in the overlapping areas of the orientated and calibrated photos. This happens by the software looking for identical points in the model area; it measures the height then restarts in a previously defined distance (in this case it was 10 m). Thus the surface model is a set of automatically measured height data which, in a forested area, also contains heights measured in the canopy. If there is a DEM available of the area the difference of the two provides information on tree height while comparing digital surface models from two different years shows us the changes in tree height and the spatial distribution of these changes.

DISCUSSION AND RESULTS

By subtracting the elevation model from the surface model we got digital tree height maps (*Fig. 3*). The areas of the settlements founded in places of earlier clear-cuttings are clearly visible (Répáshuta in the middle and Bükkszentkereszt on the right, with an approximately zero height difference). Even without quantifying the change it is clear that the height (and so the age) of the area's forests generally increased due to the foundation of the national park and the following sustainable management.

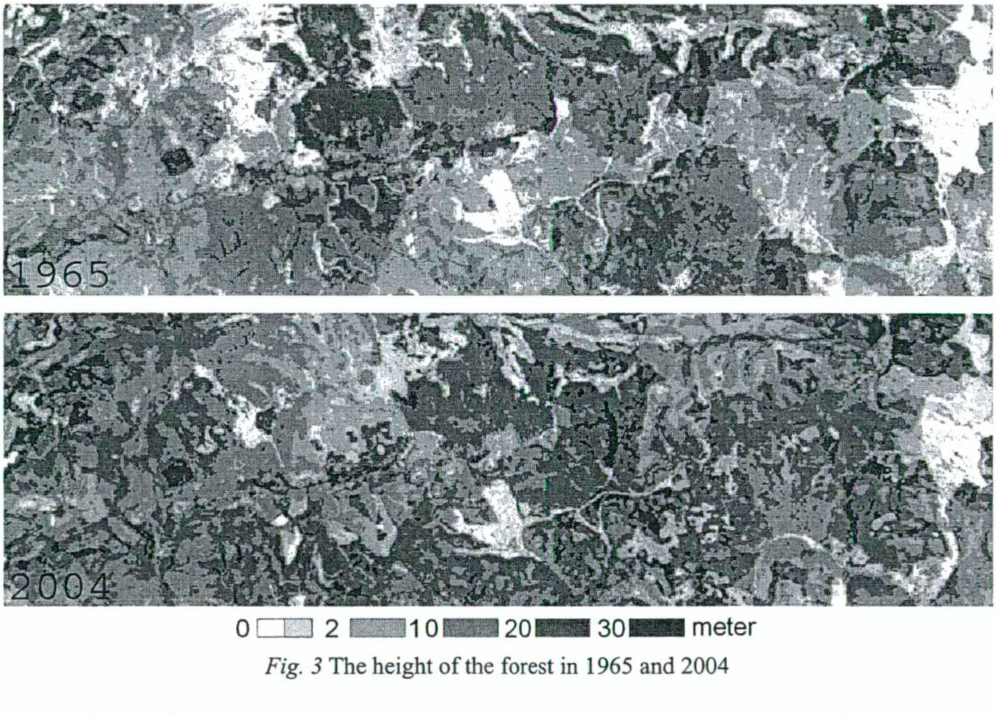

Fig. 3 The height of the forest in 1965 and 2004

On the basis of the tree height maps we drew the frequency distribution of the heights (*Fig. 4*). This shows a 7% increase in the proportion of forested areas. Maximum tree heights correspond to the maximum values shown in the yield tables for beech (40 meters in the case of a 120 year-old beech tree). By analysing the chart we can state that while in 1965 two dominant groups could be distinguished (an older with trees of 15-20 m height and a younger with 5-10 m high trees); in 2004 these two maximums are united in one, with twice the value. The explanation for this is probably that after the huge clear-cuttings related to the world war, fast-growing beech types were planted that reached the heights of earlier planted stands by 2004.

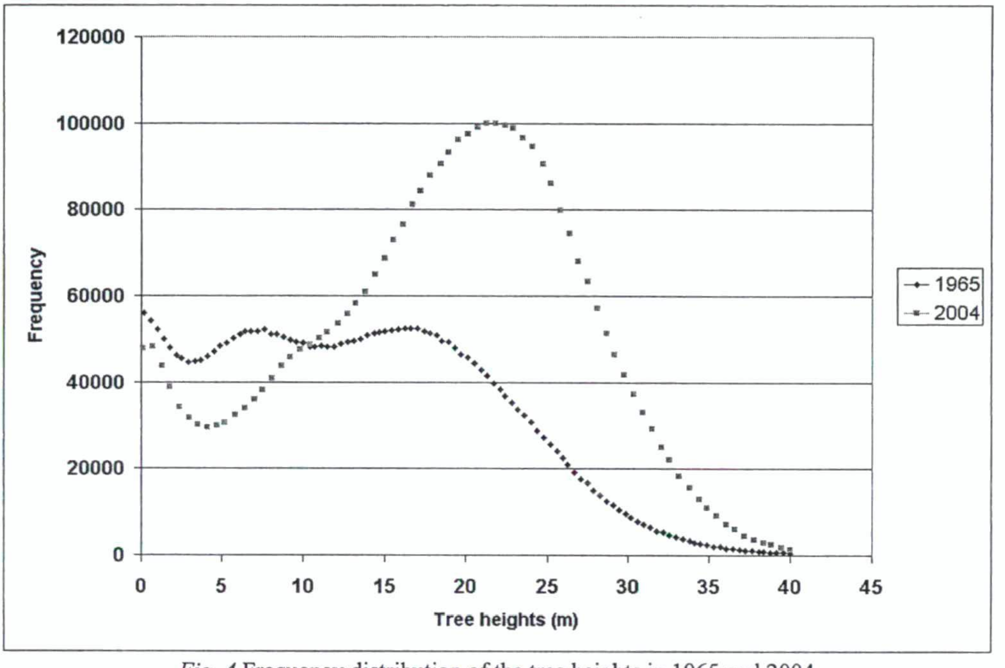

Fig. 4 Frequency distribution of the tree heights in 1965 and 2004

The height difference between the surface models serves with information on tree growth (in the case of negative values it shows traces of logging). The data show that logging occurred on 22% (20.40 km^2) of the study area (*Fig. 5*).

The changes in growth rates are the consequences of the following factors' interaction:

1. Tree species (90% of the area's forests consist of European beech – *Fagus sylvatica*)
2. The age of the forest (the growth of young trees is faster than that of old ones so the year of plantation is an essential information)
3. The characteristics of the production site (basically defined by the climate, soil and elevation) which can vary within a short distance

Thus the knowledge of the first two (e.g. species and age) along with a knowledge of the species-specific growth rates can help us to predict site characteristics. In the case of forests that consist of trees of the same age and species we can even distinguish different types of production sites. *Keveiné Bárány et al.* (2003) analysed production site data from the Aggtelek National Park area and proved that some of the local forests do not suit the ecological characteristics of the land.

In addition to the creation of the digital surface models we also prepared the orthophoto mosaic of the study area out of the aerial images. This enables us to carry out a quick visual analysis of the changes that occurred in the area between 1965 and 2004. The most recent photos suggest that the various non-native coniferous species are gradually retreating (*Fig. 6*). Stands consisting of such species are not regenerated while a natural reforestation by native species is also evident.

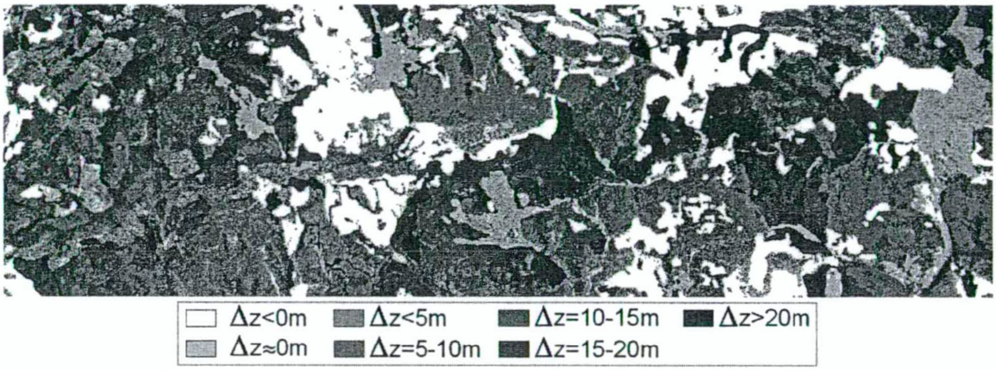

Fig. 5 Changes in tree heights (logging Δz<0, constant Δz≈0, increase Δz>0) 1965-2004

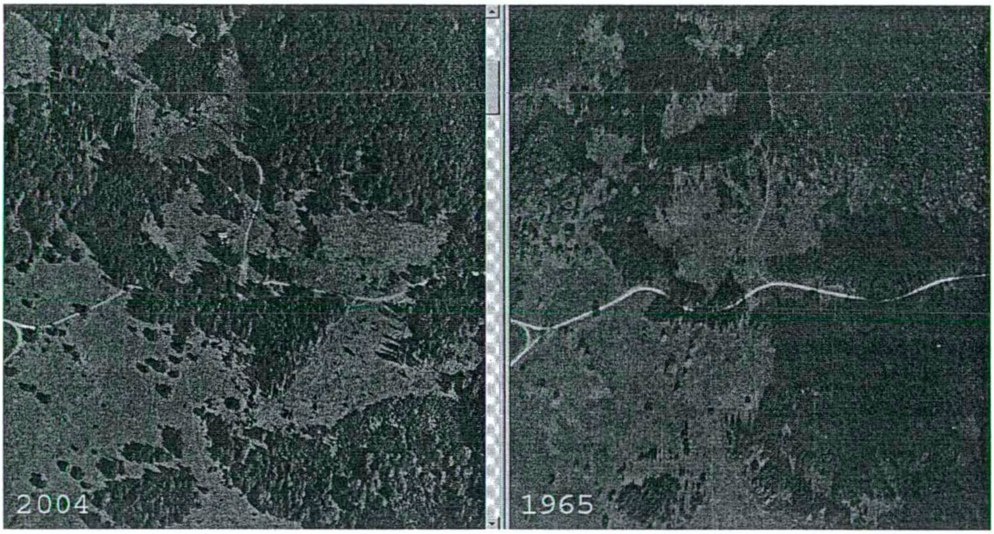

Fig. 6 Orthophotos of a small part of the investigation area (Nagy-mező), in 2004 and 1965

CONCLUSION

1. Tree height maps created from digital surface models can be effectively used in the field of forest management as a complementary method for field measurement and analysis carried out by manual instruments.
2. To define differences in tree growth rates the influence of local factors should be further investigated and, in case of regular bias, local functions should be explored.

3. Knowledge of the differences of tree growth in different production sites provides a unique opportunity to extend optimisation investigations in karstlands.
4. On the basis of the orthophoto series and the maps showing tree height changes we can conclude an increase in the proportion of forests, and the gradual disappearance of degraded vegetation patches of the karst area.

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SOME KARST SPRING ANALYSIS AT THE PEIDMONT OF BÜKK MOUNTAINS

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Összefoglalás – Sok karsztforrás található a Bükk-hegységben, amelyek közül néhány, mint a Kács-Sályi vízrendszer jelentős szerepet játszik a Borsodi-régió vízellátásában. Előfordul itt langyos vizű, kevert vizű és hideg vizű forrás is. A rendszer működésének tanulmányozása céljából mintát gyűjtöttünk ezekből a forrásokból és néhány vízfolyásból. Elemeztük a víz teljes keménységét, Ca^{2+} és Mg^{2+} tartalmát, valamint a klorid, nátrium, kálium, foszfát, nitrát, szulfát és nehézfémtartalmát. Különbség mutatkozott a források között. A tanulmány bemutatja a vizsgált területet és a kutatást.

Summary – There are several karst springs in the Bükk Mountains. Some of these, like the system of Kács and Sály, have in important role in the drinking water supply system in the region of Borsod. Here we can find springs with lukewarm water, springs with mixed water and cold water springs. We have sampled these springs and some streams in order to learn how the system works. We analysed the total hardness, the Ca^{2+} and Mg^{2+} contents, and also the content of chloride, sodium, potassium, phosphate, nitrate, sulphate and heavy metals. There are some differences between these springs. In this article we give some general information about the research and the study area.

Key words: karst springs, hydrochemistry, pollution, discharge

INTRODUCTION

Karst water has an important role in the drinking water supply system all over the world. The Bükk Mountain, which is situated on the north part of the country, is one of the most important karst areas in Hungary. Several villages and towns get their drinking water from there. But nowadays there is an increasing human impact on natural systems, so I have to be aware of their effects on the karst, which is very sensitive not only to the quantity of the water, but also to the quality.

The study area is situated in the SE part of the Bükk piedmont (*Fig. 1*) near Kács, Sály and Lillafüred. The aim of my research is to learn the function of these springs during the year and also to observe the behaviour of the pollution from the springs along the streams. I find the karst springs by the side of a little fault line especially at Kács and Sály. There are three types of springs: springs with cold, with lukewarm and mixed water.

About this system several articles were published, but the most of them are specialised on the protection area. In 1970 the spring Vízfő- (Sály) and Alap-spring (Kács) were occupied to provide water for the drinking water supply system. However the research was not established enough so it is necessary to analyse the quality changes during the years.

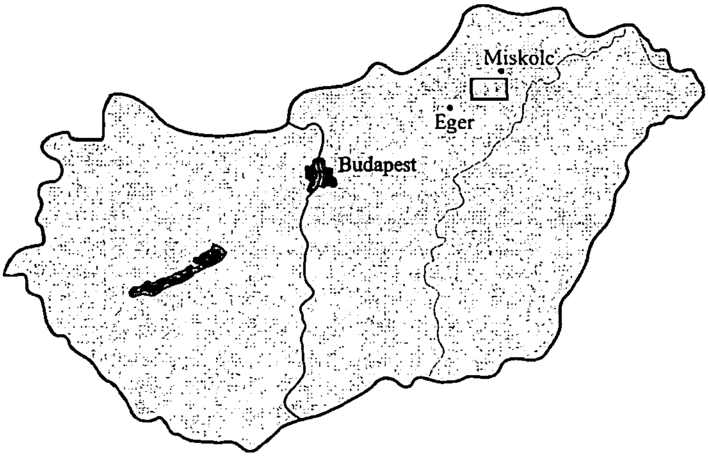


Fig. 1 The situation of the study area in Hungary

METHODS

After the data collection we realised I had not data about the water quality, which is very important, because it can help us recognise changes in the aquifer. So we decided also to analyse the chemical components of the different springs. I gather samples every two weeks at 11 points, 4 of which are points on the streams of Kács and Sály. Regular data acquisition is necessary for gaining knowledge of the function of the whole system. The other 7 points are the karst springs.

In the field I measure conductivity, pH and temperature with a RADELKIS 104 Type II instrument. After, according to the method of *Hoffmann and Pellegrin* (1996), I measure the Total Hardness, Ca, Mg, HCO_3 ions with titration.

In the laboratory I analyse the water within 24 hours, because I do not add any acid to the samples. Heavy metal content (Cd, Zn, Ni, Pb and Cu), sodium, and potassium are determined by AAS (PERKIN ELMER 3110). The SO_4 and PO_4 are measured by spectrophotometer HELIOS, according to *Krawczyk* (1996). The Cl is determined with titration with 0,01 mol $AgNO_3$.

PRECEDING RESEARCH

The Bükk Mountain is in the moderately humid continental climate region. The yearly sunshine duration is between 1850 and 1900 hours. The mean annual temperature is 8, 5-9, 6 °C, during the growth season it changes between 15, 5-16, 7, and it depends on the altitude and the exposition. Generally the last frost comes before 20. April, and the first freeze in autumn is after 15 October.

Annual precipitation is approximately 650mm (*Fig 2.)* and half of it falls during the growth season. In winter snow is frequent, generally there are 40-55 snow-covered days and the mean maximal thickness of the snow is 18 cm. This climate is good for growing crops and horticultural activity.

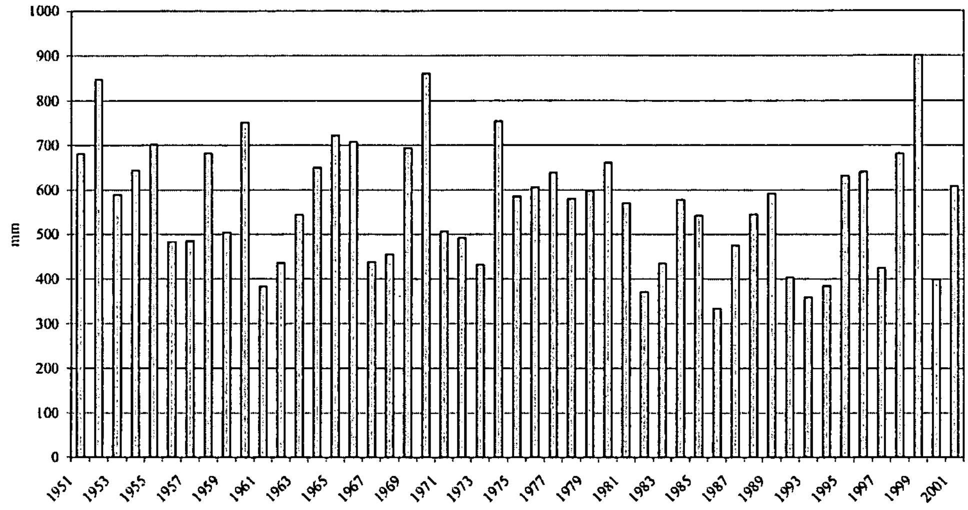


Fig. 2 The annual precipitation at Miskolc 1950-2001

The latest geological analyses have shown that in the Bükk Mountain there is not a homogeneous karst water system, but several independent systems exist. In consequence, we cannot speak about a homogeneous karst water level (*Sásdi et al.,* 2002). The system of Kács and Sály get the water from the south part of the Bükk and this water is banked up by the rhyolite tuffs, which lies on the Eocene limestone at the Bükk piedmont. In the catchment area there is dolomitic limestone, limestone with silex. According to *Rádai* (1988) this little water system has no relation with the other karst water systems around. But the latest research of *Jambik and Lénárt* (1995) has shown a relationship between the system of Miskolctapolca and Kács-Sály. Thus the former system grows at the expense of the latter. *Jambik and Lénárt* (1995) has modified some data in his work, in which he has treated the articles published so far critically. For example he has modified the superficial extent of the catchments area, because the discharge data did not verify an extent of 51.4 km^2. He presents two values for the catchment area, one before the occupations of the springs and one after: 23.8 km^2 and 16.2 km^2.

The springs rise to surface on a low altitude (f.e. 194.9 mBf) on the mountain front (*Fig. 3*). This altitude shows the lowest karst water level in the Bükk. According to *Jambik and Lénárt* (1995) the spring Tükör, which is a spring with warm water, has no more overflow water.

Here we know three types of the karst water. Springs with cold water belong to the descending precipitation water in the karst and their regime depends on the precipitation and the texture of the limestone. Their temperature is about 10-12 °C.

The second type is the mixed water springs. Their water has two sources: the precipitation and the stagnant zone. Their temperature is 14-16 °C.

Third type is springs with warm water, of which the temperature is 20-21°C. *Shcréter* (1954) has also taken measurements in these springs, and he got different values, 15-23°C. According to *Jambik and Lénárt* (1995) there is a tendency for the decrease of the temperature over time. During my field work I measure the temperature regularly, and I saw the change to be seasonal. During the winter there is really little decrease, but after the temperature increases till a certain value *(Table 1)*.

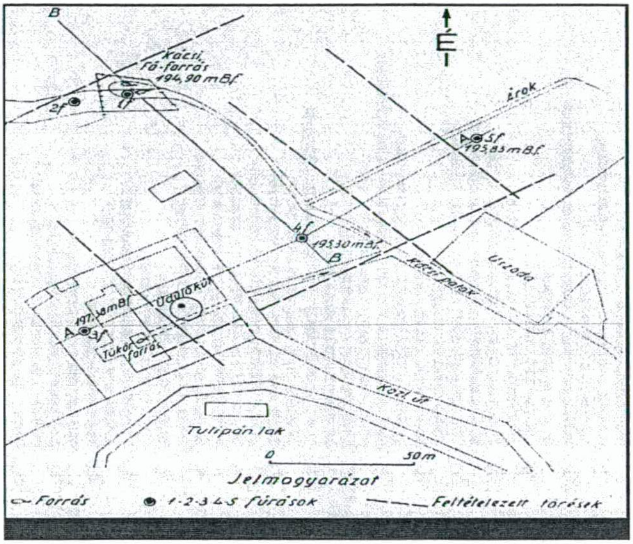


Fig. 3 Scheme of the Kács spring and the hydro-geological boreholes (after *Almássy and Scheuer,* 1967)

Table 1 The temperature of the different point of samples

Point of sample	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
S1	16	16	15	15	15,5	15,5
S2	9,5	2	2,5	0	1,5	8,5
K1	12	11	10,5	11	11,5	12
K2	16,7	14	12,75	12,5	14	15
K3	15,5	11	7,25	7	9,5	10
K4	13,5	9	7	5,5	7	12,5
K5	15	14,5	14	14	14,5	14,5
K6	20,5	20	20	18,5	20	20
K7	18	19	20	19,5	20	21
K8	21	20	20	20	20	21
B	7,5	6,5	6	6	6,5	8

For the discharge the VITUKI (Water Resources Research Center) took measurements, 1950-2000:

- discharge of warm water: 3203 l/min
- discharge of cold water: 7851 l/min

In the case of the mixed spring at Kács I have not found data for the discharge, because the warm and cold springs all break out in the bed of Kács stream, along a little fault line. Still *Aujeszky and Scheuer* (1979) mentioned values of 10000 l/min for Kács and

2500 l/min for Sály. According to *Aujeszky and Scheuer* (1979), the occupation of the karst water affected only 40% of the springs at Kács.

Hertelendi et al. (1994) analysed the age of several springs in the Bükk Mountains, including the spring Kács and Sály. He pointed out that the oldest water breaks up in the Vízfő spring at Sály, which is very interesting, because there is no such difference between the concentration of Ca and Mg ions in the spring of Kács and Sály. Furthermore at Kács there are 3-4 springs with warm water and according to other authors they are older than the other springs (*Table 2).*

Table 2 The results of the radiocarbon and tritium date calculation (*Hertelendi et al.*, 1994)

Springs	$\delta^{13}C$ [‰]	$D^{14}C$ [‰]	pMC [%]	^3H [TU]	T [°C]
Kács Alap-spring	-7.43	-403	59.4	6.6	14.8
Sály Vízfő-spring	-10.1	-563	43.5	2.9	15.9
Kács LKM-well	-9.07	-522	47.6	3.1	20.5

As we saw there are several works about the discharge and the general presentation of these springs. But there is lack of quality information about these springs. Are they really in the same system? Is there difference among the different parameters? Is there any pollution in the catchment area? Still in the reports of VITUKI (*Rádai,* 1988) there are no data for the hydrochemistry of the different springs.

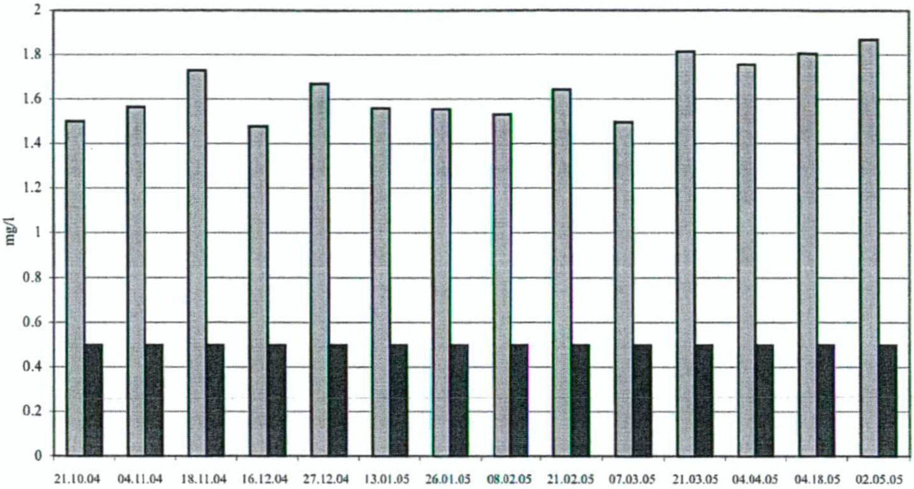
RESULTS AND DISCUSSION

As a result of the analysis I have found differences not only in the temperature of the springs, but also in the proportions of different ions. There is a difference for example in the concentration of the Na, K, PO_4, and Ca, Mg ions.

There are two samples in which the conductivity is very high, and I found these samples highly polluted with PO_4 (*Fig. 4*). In the stream of Sály and in the spring Máriás at Kács the PO_4 concentration is always very high, more than 1 mg/l, while the threshold limit value is 0.5 mg/l. It is clearly a human impact. At Kács there is no sewer system, while at Sály there is an illegal waste deposit. In the sample taken from the Kács stream there is a tendency of increasing PO_4 contamination. Besides the stream Kács and Sály there are arable land, which are treated with artificial fertilizer (rich in NO_3 and PO_4), but the main source of the PO_4 is the households.

As to the carbonate system, the values are very similar in the whole system. Generally the whole system moves together the same way. However, there is an exception: the spring Máriás at Kács has a content of Ca and Mg higher than the other springs. Total Hardness changes between 6-7.2 meq/l, while in the former spring its value is between 8.9-10.4 meq/l. The proportions of the Ca and Mg ions are relatively high, but here I find three types of karts springs. The spring Bársonyos at Lillafüred behaves like a "normal" karst spring with descending waters, namely the Mg ion concentration is low, 0.2-04 meq/l. The second type is the spring Vízfő at Sály, here the proportion of Mg ion is 3-2 meq/l, which is a characteristic of the springs from dolomite areas. It might also mean that this water is older than the others, and it probably comes from the ascending waters. In the third group there are four springs, which have a Mg ion concentration of 1-1.5 meq/l (*Fig. 5*).

A



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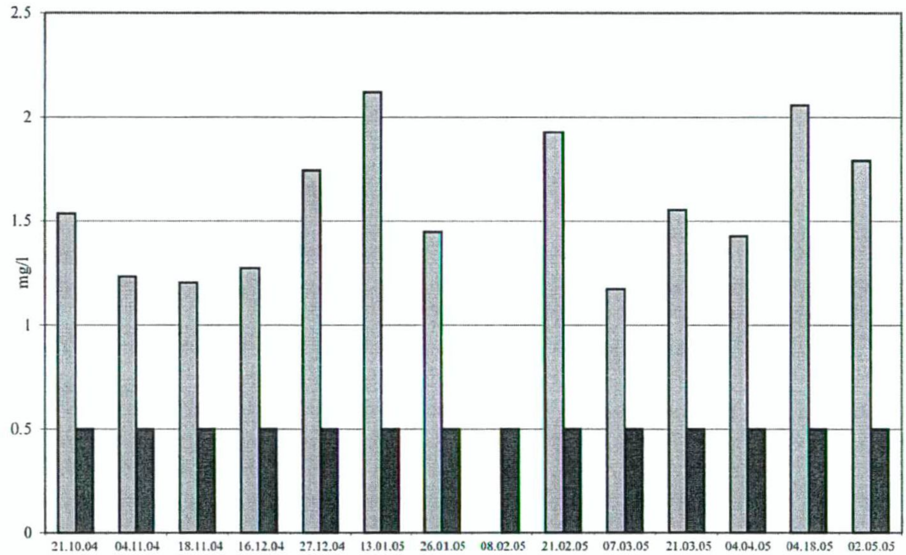

Fig. 4 The contents (grey) and the limit values (black) of PO_4 in the spring Máriás (A) at Kács and in the stream of Sály (B)

At the University of Miskolc there was a project to analyse the radon concentration of the different springs of Bükk (*Lénárt,* 1992) (*Table 4*).

Table 4 The results of the radon measurements of *Lénárt* (1992)

Springs	Date	Number of measurements	Rn mean kBq/m3	Rn max.kBq/m3	Rn min. kBq/m^3	T mean °C
Kács Alap-spring	05.05.1991	10	2,18	2,89	0,69	14,7
Kács Tükör-spring	05.05.1991	10	2,76	3,78	1,39	20,9
Sály Vízfő-spring	05.05.1991	8	4,09	7,59	3,34	15,7

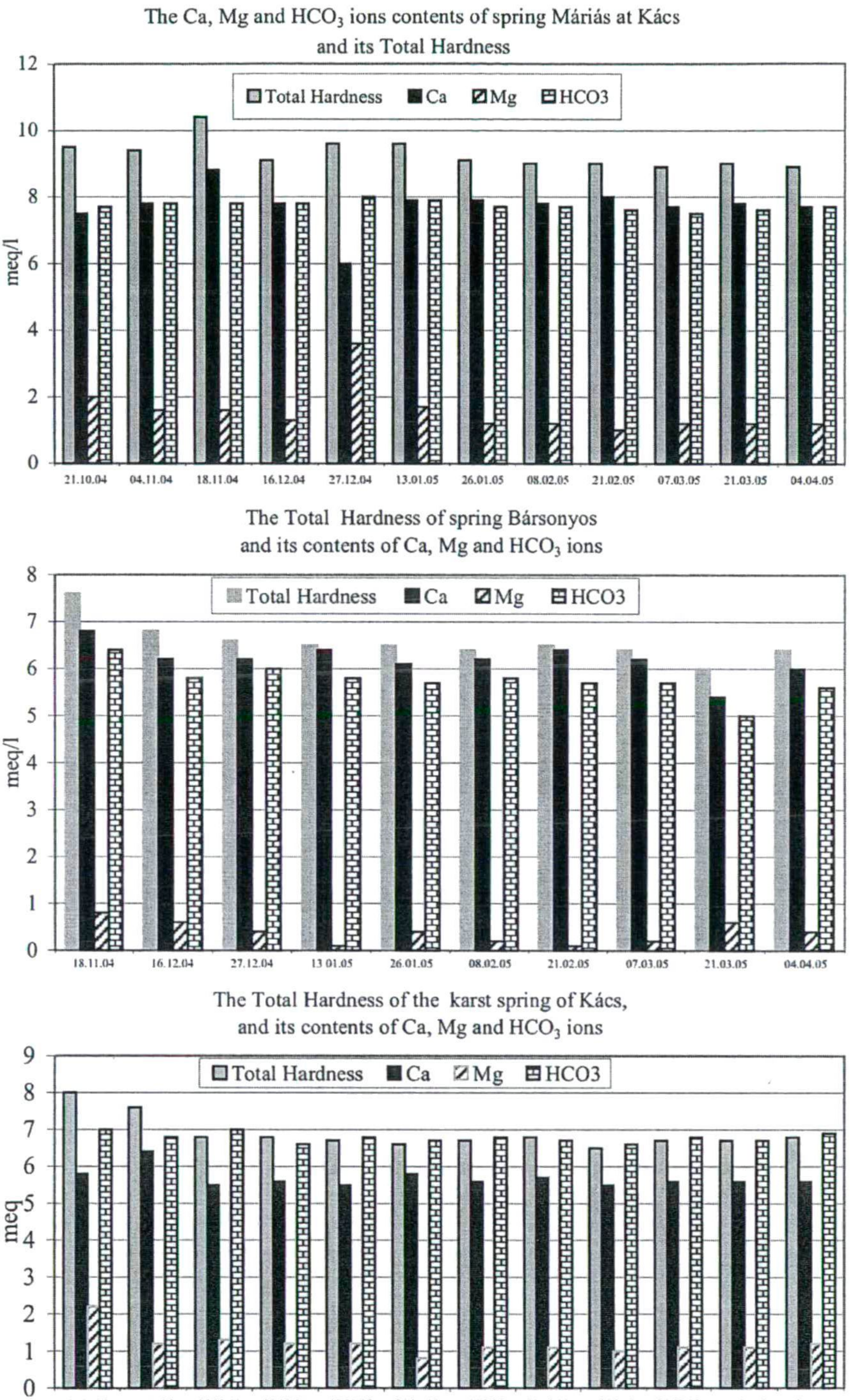

Fig. 5 The Ca, Mg and HCO_3 ions contents of some karsts springs at Kács and Sály

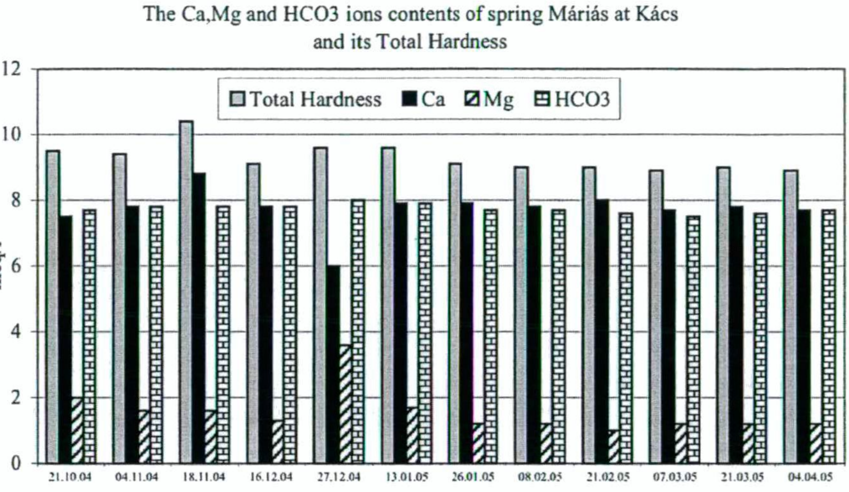

Fig. 5 (continued)

Table 5 The heavy metal concentration of some spring and stream at Kács and Sály

spring Máriás	21.10.2004	04.11.2004	18.11.2004	16.12.2004	27.12.2004	13.01.2005	26.01.2005
Cd μg/l	58.61	0.8	20.57	5.673	1.714	0	1.914
Ni μg/l	0	0	0	0	0	0	0
Zn μg/l	108.9	153.9	11.85	151.5	221.5	29.32	57.63
Cu μg/l	20.69	21.03	6.546	44.01	36.02	43.1	40.88
Pb μg/l		605.9	43.19	38.62	69.14	78.46	96.23
stream Sály	**21.10.2004**	**04.11.2004**	**18.11.2004**	**16.12.2004**	**27.12.2004**	**13.01.2005**	**26.01.2005**
Cd μg/l	0	64.57	0	2.616	7.429	1.837	0
Ni μg/l	0	0	0	0	0	0	0
Zn μg/l	27.41	193.1	77	114.7	163	83.17	103.3
Cu μg/l	9.776	24.39	11.52	42.07	62.97	32.61	41.56
Pb μg/l		1401	0	39.99	59.94	85.83	95.25
spring Kács	**04.11.2004**	**18.11.2004**	**16.12.2004**	**27.12.2004**	**13.01.2005**	**26.01.2005**	**08.02.2005**
Cd μg/l	70.25	14.93	3.141	0	0	0.367	2.208
Ni μg/l	0	0	0	0	0		84.18
Zn μg/l	166.5	27.54	204.9	23.28	38.93	82.9	22.34
Cu μg/l	16.21	12.6	55.79	14.04	19.1	18.9	0
Pb μg/l		32.67	50.29	42.82	67.11	97.92	15.65
spring Vízfő Sály	**21.10.2004**	**04.11.2004**	**16.12.2004**	**27.12.2004**	**13.01.2005**	**26.01.2005**	**08.02.2005**
Cd μg/l	52.1	33.37	9.32	3.388	0.634	0	7.629
Ni μg/l	0	0	0	0	0	0	82.73
Zn μg/l	34.75	121.1	122.7	223.5	91.01	111.3	17.02
Cu μg/l	19.38	0.984	35.03	52.97	29.37	35.6	0
Pb μg/l			22.62	62.89	67.23	68.9	11.99

The radon content of the water depends on the U-238 and Ra-226 content of the stone, the time of storage in the deep karst or in the aquifer, and the content of Ra-226 dissolved in the water.

I also measured the heavy metal content. According to *Merian* (1984) the heavy metal content in the limestone is: Cu: 4, Cd: 0.165, Ni: 15, Pb: 5, Zn: 23 ppm. According to *Brümmer et al.* (1991) the mobility of heavy metal changes with the pH: Cd pH<6-6.5; Ni, Zn pH<5.5; Cu pH<4,5; Pb pH<4 will be movable. In our samples the pH varies between 6.9 and 8.2, at which heavy metal are not soluble. We determined the following heavy metals in our samples: Ni, Zn, Cd, Cu and Pb. During the period of snow the heavy metal content diminished, some components, like Ni, have disappeared. But with the melting of the snow there is a great increase in these values. This is also true for the other components measured. Lead concentration is relatively high in the whole system, which can be result of the human impact on the catchment area, but I do not know the exact source (*Table 5*). The coloured cells are the values higher than the threshold limit according to the law *10/2000 (VI/2)*.

CONCLUSION

As I have written before, there are two mixed-water springs and according to *Jambik and Lénárt* (1995) the spring Kács gets its water mostly from descending waters. But according to our observations the precipitation and the melting of the snow arrive with a difference of approximately two months. This period can be detected in the changes of each parameter.

The data shown in this essay form part of a complex research, which I have just begun. The results bring up other questions, for example: What is the source of pollution? Thus I have to extend my research to more fields.

I have to pay attention to the pollutants, their movements in time and space, because these springs are connected to the drinking water supply system of the region Borsod. The lead and nickel concentrations are distressing and it is urgent to clear up the source of the pollution.

This research is a part of a more general analysis of which the aim is to explore the relation between pollution possible in the soil, in the vegetation.

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